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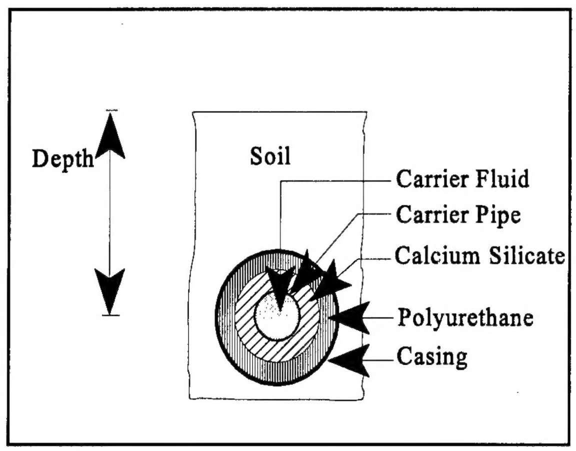
Thermal Evaluation of Piping Components Used in a Commercial Underground Heat Distribution System

by
Charles P. Marsh and Matthew W. Streibich



Super Temp-Tite heat distribution piping is the only product of its design type approved by the Federal Agency Committee for Underground Heat Distribution Systems. This system employs a water-spread-limiting (WSL) design to restrict any leakage to a single segment of piping. WSL systems are intended to withstand continuous carrier medium temperatures of up to 450 °F. On the basis of approval by the Federal Agency Committee for use at Class B, C, and D sites, the Super Temp-Tite WSL design is currently approved for the same applications by the Army Corps of Engineers. Recently the system manufacturer asked the Federal Agency Committee to approve use of its system at Class A sites—those with the harshest conditions. The U.S. Army Construction Engineering Research Laboratories (USACERL) was tasked to conduct mathematical modeling and simulations to help determine whether Super Temp-Tite meets the technical specifications for Class A applications.

It is concluded that the polyurethane foam insulation in this WSL design would be exposed to temperatures well exceeding conservative design values, both in Class A applications and for operating temperatures below 350 °F. Consequently, the system as now designed is not recommended for approval by the Federal Agency Committee.

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Super Temp-Tite heat distribution piping is the only product of its design type approved by the Federal Agency Committee for Underground Heat Distribution Systems. This system employs a water-spread-limiting (WSL) design to restrict any leakage to a single segment of piping. WSL systems are intended to withstand continuous carrier medium temperatures of up to 450 °F. On the basis of approval by the Federal Agency Committee for use at Class B, C, and D sites, the Super Temp-Tite WSL design is currently approved for the same applications by the Army Corps of Engineers. Recently the system manufacturer asked the Federal Agency Committee to approve use of its system at Class A sites—those with the harshest conditions. The U.S. Army Construction Engineering Research Laboratories (USACERL) was tasked to conduct mathematical modeling and simulations to help determine whether Super Temp-Tite meets the technical specifications for Class A applications.

It is concluded that the polyurethane foam insulation in this WSL design would be exposed to temperatures well exceeding conservative design values, both in Class A applications and for operating temperatures below 350 °F. Consequently, the system as now designed is not recommended for approval by the Federal Agency Committee.

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Foreword

This study was conducted for Headquarters, U.S. Army Corps of Engineers under Reimbursable Work Unit JN5, "Investigation of Fiber-Reinforced Plastic Condensate Return Carrier Piping." The technical monitor was Dale Otterness, CEMP-ET.

The work was performed by the Materials Science and Technology Division (FL-M) of the Facilities Technology Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). A portion of this work was performed under contract to USACERL by NMD & Associates, 2001 Paul Springs Parkway, Alexandria, VA 22308. Dr. Ilker R. Adiguzel is Acting Chief, CECER-FL-M, and Donald F. Fournier is Acting Operations Chief, CECER-FL. The USACERL technical editor was Gordon L. Cohen, Technical Information Team.

COL James T. Scott is Commander of USACERL, and Dr. Michael J. O'Connor is Director.

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1 Introduction

Background

Super Temp-Tite heat distribution piping* is the only product of its design type approved by the *Federal Agency Committee for Underground Heat Distribution Systems*. This commercial piping system employs a water-spread-limiting (WSL) design that is intended to restrict any leakage to a single segment of piping (Phetteplace and Carbee 1992).

The Super Temp-Tite system comprises a steel carrier pipe encased in a layer of calcium silicate insulation; the calcium silicate is sheathed with a layer of polyurethane foam insulation, and the entire system is clad with a reinforced thermosetting resin plastic casing (as shown in the cross-sectional view in Chapter 2, Figure 1). These expansion joints are designed to take up thermal expansion by allowing the piping to expand into brass couplings without the use of right-angle bends or thermal-expansion loops. Mounted to each end of the 20-ft carrier pipe sections are a Teflon®-coated stainless steel sealing ring and an EPDM (ethylene propylene diene monomer) cleaning ring, both of which fit inside the brass coupling. Each coupling is held in place by a "lock block" consisting of a mixture of pearlite and epoxy resin.

WSL piping systems are designed for direct-buried use, and are intended to withstand continuous carrier medium operating temperatures of up to 450 °F. Full information on system design, installation, and field repair can be found in the manufacturer's system brochure (TPS Inc. 1989). The system design brochure specifies the various insulation thicknesses associated with nominal carrier pipe diameters of 3, 4, 6, 8, 10, and 12 in. (see Chapter 2, Table 1).

On the basis of approval by the Federal Agency Committee for use at Class B, C, and D sites, the Super Temp-Tite WSL design is currently approved for the same applications by Corps of Engineers Guide Specification (CEGS) 02695, *Preapproved Underground Heat Distribution Systems*. Recently the system manufacturer asked the Federal Agency Committee to approve use of the Super Temp-Tite system at

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* Super Temp-Tite is a trademark of Thermal Pipe Systems, Inc., 505 New Churchmans Rd., New Castle, DE 19720.

Class A sites as defined in CEGS 02695. Class A sites present the most severe conditions, with water tables expected periodically to rise above the bottom of the system, and surface water expected to accumulate and remain for long periods of time in the soil surrounding the system.

The Federal Agency Committee tasked the U.S. Army Construction Engineering Research Laboratories (USACERL) to conduct mathematical modeling and simulations to help determine whether Super Temp-Tite meets the technical specifications for use at Class A sites.

Objectives

The objectives of this study were to:

- provide a preliminary engineering analysis pertaining to the suitability of the Super Temp-Tite system for use at Class A sites
- accurately model the radial temperature profile of the Super Temp-Tite system in characteristic service conditions for six stock carrier pipe diameters
- provide a recommendation to the Federal Agency Committee regarding the approval of the subject system for Class A applications.

Approach

A preliminary evaluation of the WSL system design brochure for use on Class A sites (TPS Inc. 1989) was conducted by an independent contractor (see Appendix A).

The theoretical analysis models the radial steady-state temperature profile and employs design parameters stated in the company brochure for the various nominal carrier pipe diameters. This analysis applies only to the piping between the couplings. No attempt was made to estimate the temperature profile within the couplings.

This WSL system was modeled as a one dimensional steady-state heat conduction problem. The following assumptions were made:

- the soil was assumed to be a large homogeneous cylinder surrounding the piping system with a radius equal to the burial depth (see Chapter 2, Figure 2)
- each of the different materials was assumed to have a constant thermal conductivity and a negligible contact resistance at their interfaces

- the temperature of the inner wall of the carrier pipe was assumed to be equal to the temperature of the carrier fluid
- the temperature of the outer radius of the soil was assumed to be 60 °F.

Calculations were performed for representative system configurations for each of the six different carrier pipe diameters. The burial depth, carrier fluid temperature, and soil conductivity were varied to represent the range of conditions that the piping would typically experience while in service. One should note that the thermal conductivity for calcium silicate varies with temperature. Because the temperature of the calcium silicate varies significantly between its inner and outer radii, the value of the thermal conductivity of calcium silicate was chosen at a temperature conservatively below each of the carrier fluid temperatures. The thermal conductivity value for 300 °F was used for the case of 350 °F fluid temperature, while the value for 350 °F was used for the 450 °F fluid temperature. The configuration for the representative system, based on the manufacturer's system design brochure, was as follows:

Carrier fluid temperature	350 & 450 °F
Burial depth	2 & 6 feet
Soil thermal conductivity	5, 10, & 15 BTU in/hr ft^2 °F
Pipe thermal conductivity	300 BTU in/hr ft^2 °F
Calcium silicate thermal conductivity	0.44 BTU in/hr ft^2 °F for 350 °F fluid
Calcium silicate thermal conductivity	0.46 BTU in/hr ft^2 °F for 450 °F fluid
Polyurethane thermal conductivity	0.1415 BTU in/hr ft^2 °F
Casing thermal conductivity	1.3 BTU in/hr ft^2 °F
Soil surface temperature	60 °F

Scope

This report documents a theoretical analysis of piping configurations and operating conditions. The reader may find it useful to compare these findings with a field study underway at the U.S. Army Cold Regions Engineering Laboratory (USACRREL), Hanover, NH. (Results of the USACRREL field study are expected by the end of Fiscal Year 1996.)

This analysis applies only to the piping, and does not address the temperature profile within the expansion joints. This study was not intended to consider all possible extremes of conditions that a complete design analysis would typically include. A more detailed treatment of the soil and surface effects is beyond the scope of this study.

Units of Weight and Measure

U.S. standard units of weight and measure are used in this report. A table of conversion factors for standard international (SI) units is presented below.

SI conversion factors

1 in.	=	25.4 mm
1 ft	=	0.305 m
1 lb	=	0.453 kg
1 gal	=	3.78 L
1 psi	=	6.89 kPa
°F	=	(°C × 1.8) +32

Equation Symbols and Variables

The symbols and variables used in this report are defined in the table below.

Definition of mathematical symbols and variables.

Symbol	Definition
C	Arbitrary constant
k	Thermal conductivity [BTU-in/hr-ft^2-°F]
k_n	Thermal conductivity of n^{th} material region [BTU-in/hr-ft^2-°F]
T	Temperature [°F]
T_n	Temperature in n^{th} material region [°F]
r	Radius [in.]
r_n	Outer radius of n^{th} material region [in.]

2 Temperature Distribution

Piping Specifications

Figure 1 is an illustration (not to scale) of the basic Super Temp-Tite piping configuration. Figure 2 presents an illustration of the system as modeled in this analysis, including indications of the radii expressed in the equations that follow. Table 1 lists the thicknesses of pipe insulation and casing for six different pipe diameters, as specified in the TPS Inc. system brochure (1989). These illustrations and specifications also apply to the analysis in Chapter 3.

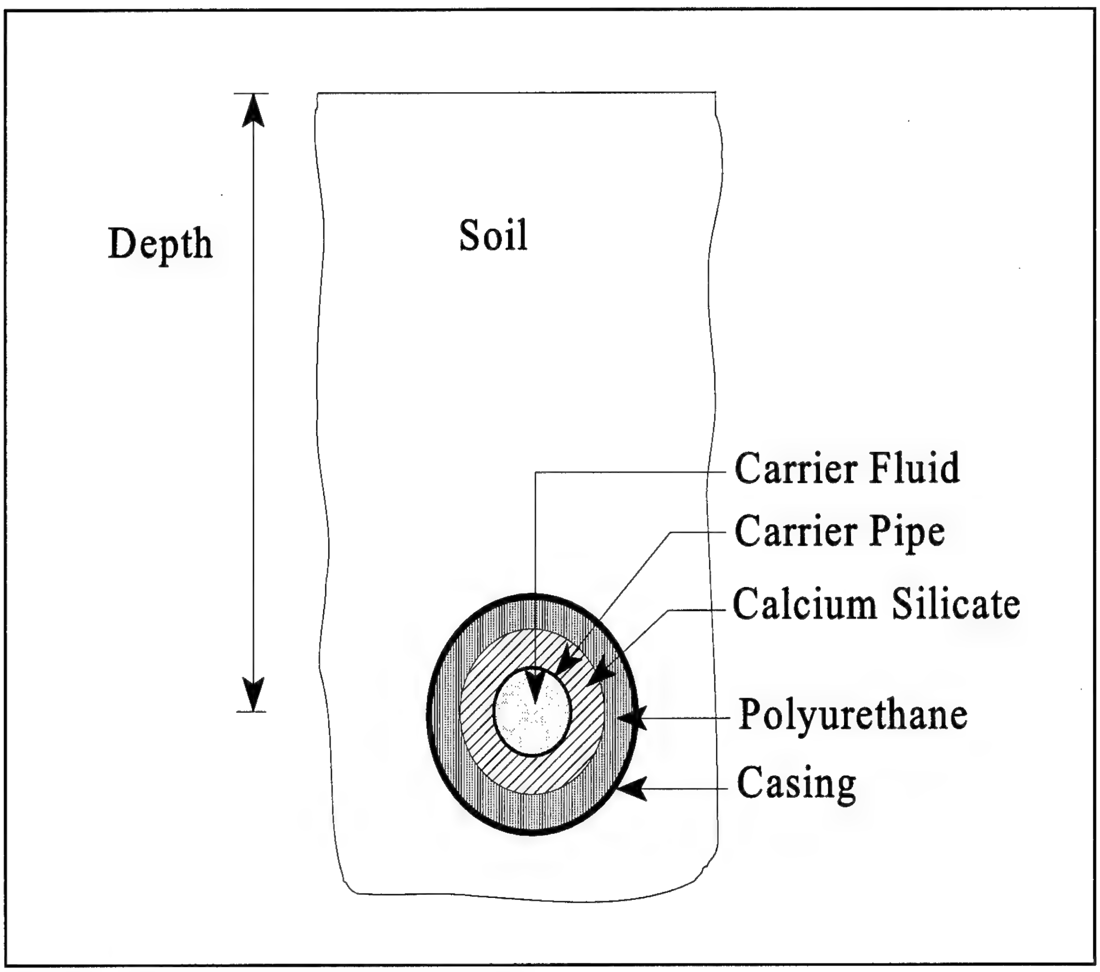

Figure 1. Super Temp-Tite piping configuration.

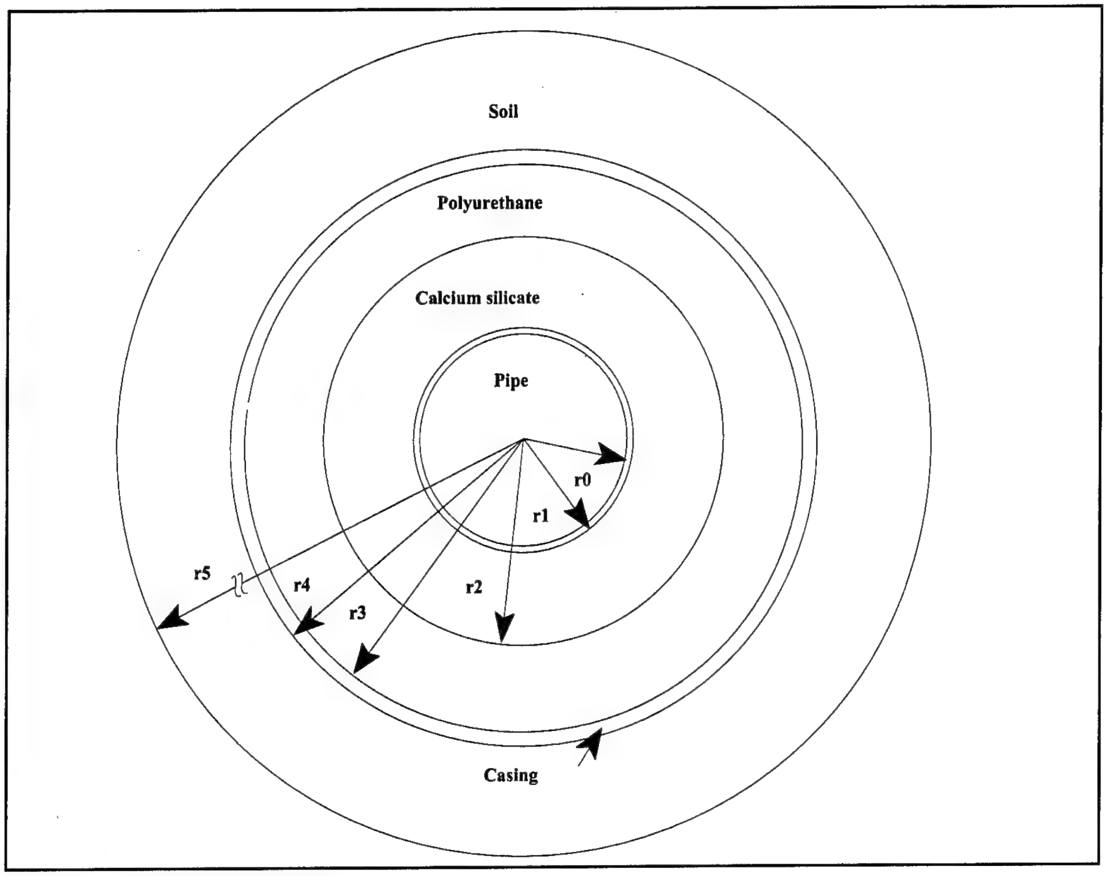

Figure 2. Model for analysis.

Analysis

For the case of an n-region hollow cylinder with given surface temperatures at the inner and outer radii, the appropriate form of the heat equation within each of the n material regions may be expressed as

$$\frac{1}{r}\frac{d}{dr}\left(k_n r \frac{dT}{dr}\right) = 0 \qquad \text{[Eq 1]}$$

Table 1. Thickness of insulation and casing for Super Temp-Tite design.

Pipe Size [in.]	Calcium Silicate Thickness [in.]	Polyurethane Thickness [in.]	Casing Thickness [in.]
3	1.00	1.27	0.1900
4	1.00	1.27	0.1900
6	1.50	1.27	0.1875
8	2.00	1.73	0.2500
10	2.50	1.18	0.1950
12	2.50	1.18	0.1950

The general solution of Eq 1 for each n-region (Incropera 1990), assuming constant thermal conductivity within those regions, is

$$T_n(r) = C_1 \ln(r) + C_2 \qquad \text{[Eq 2]}$$

In the system under study, there were five different material regions (see Figure 2). In order to specify the situation completely it is necessary to determine the values of ten constants. To do this, at least ten boundary conditions must be considered. The boundary conditions used here assume that (1) temperatures are equal at the inner and outer radii of all surfaces, (2) carrier medium and soil temperatures over the entire system are constant, discounting insignificant localized gradients, (3) there is no contact resistance at the various material interfaces, and (4) heat energy is neither created or destroyed during steady-state flow. These boundary conditions are expressed as follows:

$$T_1(r_o) = 350 \text{ or } 450°\text{F} \qquad \text{[Eq 3]}$$

$$T_n(r_n) = T_{n+1}(r_n) \qquad n = 1\text{-}4 \qquad \text{[Eq 4]}$$

$$k_n \left.\frac{dT_n}{dr}\right]_{r_n} = k_{n+1} \left.\frac{dT_{n+1}}{dr}\right]_{r_n} \qquad n = 1\text{-}4 \qquad \text{[Eq 5]}$$

$$T_5(r_5) = 60°\text{F} \qquad \text{[Eq 6]}$$

Results

From the stated equations and boundary conditions, the general temperature profiles for the piping system were found. A spreadsheet was used to calculate and plot the temperature profiles for the different carrier pipe diameters, soil conductivities, burial depths, and carrier pipe fluid temperatures (see Appendix B).

Using the insulation thickness values in Table 1, it was found that the temperatures at the calcium silicate/polyurethane foam interface were about 265 °F to 350 °F for carrier fluid temperatures of 350 °F and 450 °F, respectively. These temperatures are in excess of the long-term, continuous-use temperature for polyurethane foam insulation. As shown in Tables 2–4, the maximum temperature of the polyurethane

Table 2. Maximum temperature experienced by polyurethane insulation for 350 °F and 450 °F carrier medium temperatures (k_{soil} = 5 BTU in/hr ft^ 2 °F).

Carrier Pipe Diameter	T_1(supply) = 350 °F	T_1(supply) = 450 °F
3	281	360
4	285	366
6	268	344
8	267	342
10	240	306
12	243	310

Table 3. Maximum temperature experienced by polyurethane insulation for 350 °F and 450 °F carrier medium temperatures (k_{soil} = 10 BTU in/hr ft^ 2 °F).

Carrier Pipe Diameter	T_1(supply) = 350 °F	T_1(supply) = 450 °F
3	276	354
4	280	359
6	261	334
8	261	334
10	229	291
12	232	295

Table 4. Maximum temperature experienced by polyurethane insulation for 350 °F and 450 °F carrier medium temperatures (k_{soil} = 15 BTU in/hr ft^ 2 °F).

Carrier Pipe Diameter	T_1(supply) = 350 °F	T_1(supply) = 450 °F
3	274	351
4	278	357
6	258	331
8	258	331
10	225	286
12	227	289

foam varied considerably depending upon the system's pipe diameter and soil conductivity.

From these results it can be seen that the calcium silicate thickness needs to be increased in order to lower the maximum temperature experienced by the polyurethane insulation to a value well within its specified operating limits. Because the manufacturer did not specify a temperature limit for this insulation (TPS Inc. 1989), this study uses a conservative value of 200 °F as the maximum long-term continuous-use temperature for polyurethane insulation. Additional calculations are included for when it is assumed that the limiting temperature is 250 °F.

Error Analysis

For this estimation it was assumed that some effects were negligible and could be ignored without seriously affecting the results. The first assumption was that the carrier pipe inner wall convective heat-transfer coefficient is negligible. The thermal conductivity of steel is 300 Btu in/hr ft^ 2 °F and the inner wall convective coefficient is approximately 1400 Btu/hr ft^ 2 °F (Research Associates 1991). As a result the net effect of including this aspect would be a minor temperature decrease—not more than approximately 2 °F for all cases examined.

Another factor not considered is the contact resistance associated with the material interfaces. Without more detailed information characterizing the interfaces that include polyurethane foam insulation, reliably accounting for this factor would be difficult. If a contact resistance factor were included, the result would be to impede heat transfer and raise the temperature profile.

A final source of potential error involves the assumption that the heat transfer through soil may be modelled as a hollow cylinder of diameters of 2 ft and 6 ft, with a constant outside temperature of 60 °F. Given that soil temperature often exceeds this value, the assumption leads to a slight overestimation of the heat loss, lowering the temperature profile.

3 Calcium Silicate Thickness Requirements

Analysis

To calculate the minimum thickness of the calcium silicate required to limit the maximum temperature of the polyurethane to either 250 °F or 200 °F, the same system of equations for each case in Chapter 2 was used, but the thickness of the calcium silicate and polyurethane foam were also variables. The calculations were executed in such a way as to keep the diameter of the conduit constant. Therefore, as the thickness of the calcium silicate increased, the thickness of the polyurethane foam decreased by the same amount. Consequently, another constraint had to be applied to solve for the minimum thickness: the temperature at the calcium silicate/ polyurethane foam interface, r_2 must equal either 250 °F or 200 °F.

$$T_2(r_2) = 250°F \qquad \text{[Eq 7]}$$

$$T_2(r_2) = 200°F \qquad \text{[Eq 8]}$$

From this system of equations, the minimum thickness of the calcium silicate was calculated numerically.

Results

Tables 5–10 show the results of the thickness calculations for the 250 °F case compared to present system design. It can be seen that calcium silicate thickness needs to be increased for the smaller pipe diameters with a 350 °F carrier fluid temperature (independent of soil conductivity). The two largest diameters have an adequate thickness of calcium silicate for this case. For carrier fluid temperatures of 450 °F, the thickness of the calcium silicate needs to be increased, independent of soil conductivity, by a minimum of 10 percent to a maximum of over 80 percent.

Tables 11–16 show the results of the thickness calculations for the 200 °F case compared to the present system design. It can be seen that the thickness of the

calcium silicate needs to be increased, independent of soil conductivity, by a minimum of 9 percent for carrier fluid temperatures of 350 °F to a maximum of over 100 percent to handle some cases where carrier fluid temperatures are 450 °F.

Error Analysis

The same errors that applied to the calculations in Chapter 2 apply to this calculation.

Table 5. Change in calcium silicate thickness to achieve 250 °F at polyurethane interface with soil conductivity = 5 BTU in/hr ft^2 °F and carrier temperature = 350 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.28	28%
	6	1.00	1.34	34%
4	2	1.00	1.33	33%
	6	1.00	1.40	40%
6	2	1.50	1.65	10%
	6	1.50	1.74	16%
8	2	1.75	2.17	24%
	6	1.75	2.30	31%
10	2	2.50	2.20	-12%
	6	2.50	2.34	-7%
12	2	2.50	2.23	-11%
	6	2.50	2.39	-5%

Table 6. Change in calcium silicate thickness to achieve 250 °F at polyurethane interface with soil conductivity = 10 BTU in/hr ft^2 °F and carrier temperature = 350 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.24	24%
	6	1.00	1.27	27%
4	2	1.00	1.28	28%
	6	1.00	1.31	31%
6	2	1.50	1.59	6%
	6	1.50	1.63	9%
8	2	1.75	2.11	20%
	6	1.75	2.17	24%
10	2	2.50	2.13	-15%
	6	2.50	2.21	-12%
12	2	2.50	2.16	-14%
	6	2.50	2.25	-10%

Table 7. Change in calcium silicate thickness to achieve 250 °F at polyurethane interface with soil conductivity = 15 BTU in/hr ft^2 °F and carrier temperature = 350 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.22	22%
	6	1.00	1.24	24%
4	2	1.00	1.26	26%
	6	1.00	1.28	28%
6	2	1.50	1.57	4%
	6	1.50	1.60	6%
8	2	1.75	2.09	19%
	6	1.75	2.13	22%
10	2	2.50	2.11	-16%
	6	2.50	2.16	-14%
12	2	2.50	2.14	-15%
	6	2.50	2.20	-12%

Table 8. Change in calcium silicate thickness to achieve 250 °F at polyurethane interface with soil conductivity = 5 BTU in/hr ft^2 °F and carrier temperature = 450 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.72	72%
	6	1.00	1.81	81%
4	2	1.00	1.76	76%
	6	1.00	1.86	86%
6	2	1.50	2.16	44%
	6	1.50	2.30	53%
8	2	1.75	2.86	63%
	6	1.75	3.03	73%
10	2	2.50	2.86	14%
	6	2.50	3.06	22%
12	2	2.50	2.89	15%
	6	2.50	3.11	24%

Table 9. Change in calcium silicate thickness to achieve 250 °F at polyurethane interface with soil conductivity = 10 BTU in/hr ft^2 °F and carrier temperature = 450 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.66	66%
	6	1.00	1.70	70%
4	2	1.00	1.69	69%
	6	1.00	1.74	74%
6	2	1.50	2.08	39%
	6	1.50	2.15	43%
8	2	1.75	2.78	59%
	6	1.75	2.86	63%
10	2	2.50	2.78	11%
	6	2.50	2.87	15%
12	2	2.50	2.80	12%
	6	2.50	2.91	16%

Table 10. Change in calcium silicate thickness to achieve 250 °F at polyurethane interface with soil conductivity = 15 BTU in/hr ft^2 °F and carrier temperature = 450 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.64	64%
	6	1.00	1.66	66%
4	2	1.00	1.67	67%
	6	1.00	1.70	70%
6	2	1.50	2.06	37%
	6	1.50	2.10	40%
8	2	1.75	2.75	57%
	6	1.75	2.80	60%
10	2	2.50	2.75	10%
	6	2.50	2.81	12%
12	2	2.50	2.77	11%
	6	2.50	2.84	14%

Table 11. Change in calcium silicate thickness to achieve 200 °F at polyurethane interface with soil conductivity = 5 BTU in/hr ft^2 °F and carrier temperature = 350 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.71	71%
	6	1.00	1.79	79%
4	2	1.00	1.75	75%
	6	1.00	1.85	85%
6	2	1.50	2.15	43%
	6	1.50	2.28	52%
8	2	1.75	2.84	62%
	6	1.75	3.01	72%
10	2	2.50	2.84	13%
	6	2.50	3.04	21%
12	2	2.50	2.86	14%
	6	2.50	3.09	23%

Table 12. Change in calcium silicate thickness to achieve 200 °F at polyurethane interface with soil conductivity = 10 BTU in/hr ft^2 °F and carrier temperature = 350 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.64	64%
	6	1.00	1.68	68%
4	2	1.00	1.68	68%
	6	1.00	1.73	73%
6	2	1.50	2.07	38%
	6	1.50	2.13	42%
8	2	1.75	2.75	57%
	6	1.75	2.84	62%
10	2	2.50	2.76	10%
	6	2.50	2.85	14%
12	2	2.50	2.78	11%
	6	2.50	2.89	15%

Table 13. Change in calcium silicate thickness to achieve 200 °F at polyurethane interface with soil conductivity = 15 BTU in/hr ft^2 °F and carrier temperature = 350 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.62	62%
	6	1.00	1.65	65%
4	2	1.00	1.66	66%
	6	1.00	1.69	69%
6	2	1.50	2.04	36%
	6	1.50	2.08	39%
8	2	1.75	2.73	56%
	6	1.75	2.78	59%
10	2	2.50	2.73	9%
	6	2.50	2.79	11%
12	2	2.50	2.75	10%
	6	2.50	2.82	13%

Table 14. Change in calcium silicate thickness to achieve 200 °F at polyurethane interface with soil conductivity = 5 BTU in/hr ft^2 °F and carrier temperature = 450 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.98	98%
	6	1.00	2.08	108%
4	2	1.00	2.01	101%
	6	1.00	2.12	112%
6	2	1.50	2.45	63%
	6	1.50	2.61	74%
8	2	1.75	3.24	85%
	6	1.75	3.44	96%
10	2	2.50	3.23	29%
	6	2.50	3.46	38%
12	2	2.50	3.24	30%
	6	2.50	3.50	40%

Table 15. Change in calcium silicate thickness to achieve 200 °F at polyurethane interface with soil conductivity = 10 BTU in/hr ft^2 °F and carrier temperature = 450 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.90	90%
	6	1.00	1.95	95%
4	2	1.00	1.93	93%
	6	1.00	1.98	98%
6	2	1.50	2.36	57%
	6	1.50	2.44	63%
8	2	1.75	3.14	79%
	6	1.75	3.24	85%
10	2	2.50	3.13	25%
	6	2.50	3.24	30%
12	2	2.50	3.15	26%
	6	2.50	3.27	31%

Table 16. Change in calcium silicate thickness to achieve 200 °F at polyurethane interface with soil conductivity = 15 BTU in/hr ft^2 °F and carrier temperature = 450 °F.

Nom. Pipe Dia. [in.]	Burial Depth [ft]	Current Thickness of Calcium Silicate [in.]	Required Thickness of Calcium Silicate [in.]	Percent Difference
3	2	1.00	1.87	87%
	6	1.00	1.91	91%
4	2	1.00	1.90	90%
	6	1.00	1.94	94%
6	2	1.50	2.33	55%
	6	1.50	2.38	59%
8	2	1.75	3.11	78%
	6	1.75	3.18	82%
10	2	2.50	3.10	24%
	6	2.50	3.17	27%
12	2	2.50	3.11	24%
	6	2.50	3.20	28%

4 Conclusions and Recommendations

Conclusions

Based on this analysis, it is concluded that the temperature experienced by the polyurethane foam insulation for this WSL design will be well above a conservative continuous use maximum operating temperature. This conclusion applies both to the upper limit of carrier medium temperature allowed in Class A uses (450 °F) and a typical operating temperature of 350 °F, which corresponds to a saturated steam pressure of 120 psig. The conclusion also holds for a range of temperatures below 350 °F. The calculations presented here strongly indicate that shortly after being put into service, the polyurethane insulation closest to the carrier pipe will be exposed to excessive temperatures, which in turn will cause it to degrade. Over time this degradation will adversely affect the insulating effectiveness of the polyurethane foam and will cause heat losses in excess of design values. Ongoing excess heat loss will adversely affect the total life cycle cost of any heat distribution system. The amount of extra calcium silicate insulation needed in order to limit the maximum polyurethane foam temperature to 250 °F and 200 °F has been calculated, and is found to be significant. For the carrier temperatures examined, anywhere from an additional 4 percent to 112 percent calcium silicate is needed. Alternatively, the permissible upper limit on operating temperature could be reduced to lower the amount of heat to which the polyurethane foam insulation may be exposed.

It should be noted that only the steady-state temperature profile some distance away from the expansion joints of this piping design fell within the scope of this analysis. Furthermore, a number of questions raised in the independent analysis of the system brochure (Appendix A) apparently could require a more complete examination, with an emphasis on materials temperature limitations and long-term reliability. The major concerns raised are as follows:

- lack of quantitative data on the physical properties of various materials at elevated temperatures and over time (e.g., polyurethane foam insulation, EPDM and HTRC sealing rings, silicone lubricant, RTRP with polyester isothalic resin casing, and the composite lock block)
- lack of chemical compatibility testing of the lock block composite material where in direct contact with the bronze coupling at elevated temperatures

- no estimation of temperature profile around the coupling joints where a 1–2 in. air space is present
- lack of detail on various manufacturing and installation procedures
- confusing or incomplete description of maintenance and repair procedures.

Recommendations

Based on the results of this analysis, it is recommended that the Super Temp-Tite heat distribution system, as currently designed and specified for carrier temperatures up to 450 °F, not be approved for use at Class A sites. It is further recommended that the Federal Agency Committee reevaluate its previous approval for using the system at Class B, C, and D sites.

References

Incropera, Frank P., and David P. DeWitt, *Fundamentals of Heat and Mass Transfer*, 3d ed. (John Wiley and Sons, New York, 1990).

Phetteplace, Gary, and David Carbee, *Survey of Field Experience with Thermal Pipe Systems Super Temp-Tite*, Technical Report IR1113 (U.S. Army Cold Regions Research and Engineering Laboratory, September 1992).

Research Associates, *Evaluation of Heat Losses from Army UHDS Systems*, contractor report for U.S. Army Construction Engineering Research Laboratories (November 1991.)

Thermal Pipe Systems, Inc: Super Temp-Tite Underground Prefabricated Heat Distribution Systems, system design brochure (Thermal Pipe Systems [TPS], Inc., Media, PA, May 1989).

Appendix A: Independent Engineering Evaluation of TPS Inc. Heat Distribution System Design Brochure

[Editor's note: this appendix contains the full text of an independent engineering evaluation of the Super Temp-Tite system by NMD & Associates, Alexandria, VA.]

Purpose

The purpose of this review is to consider the viability for preapproval acceptance of the described heat distribution systems within CEGS 02695 for use on class A sites. The brochure reviewed is that dated February, 1995 and titled "Super Temp-Tite - Underground Prefabricated Heat Distribution Systems". The brochure describes a conduit system for high temperature water and steam lines ("Super Temp-Tite") and two condensate return line conduit ("Sch 80 Heat-Tite" and "RTRP Vee-Tite"). Comments are based in an expected reliable and energy efficient life of 25 years. A class A site is the most severe of four site classifications and is designated when the water table is either frequently or occasionally above the bottom of the system and when surface water is expected to accumulate and remain for long periods in the soil surrounding the system. Super Temp-Tite conduit is presented as suitable for system temperatures up to 450 °F. while condensate return conduits are limited to a temperature of 250 °F.

General Conclusion

The content of the brochure does not provide sufficient data to show acceptability for use of this product in Class A sites. The lack of relative data should also preclude the use of the product in less severe B, C, D sites.

The major problem involves the failure to indicate the physical properties of materials at the temperatures to

which they would be subjected under normal system operation. Also, aging tests were of very short duration and, even though significant degradation was evident, no attempt was made to extrapolate the data to estimate anticipated useful life. The brochure inadequacies primarily concern the materials, design, and construction of the conduit system and are independent of external site conditions.

Specific Comments

a. Super Temp-Tite Conduit. (for steam and hot water up to 450 °F.). The conduit consists of 20 foot sections composed of steel heat carrying pipe, a layer of calcium silicate insulation, a layer of polyurethane foam, and a fiberglass casing. The casing ends contain an annulus sealing ring extending from the pipe to the casing and made of ethylene propylene diene monomer (EPDM). The sections are joined with a bronze coupling into which the steel carrier pipes are free to slide with the aid of a silicone lubricant. Sealing each pipe in the coupling are two O-rings. One O-ring is of a high temperature rubber compound (HTRC) having a circular cross-section while the other consists of a Teflon® encased stainless steel spring with a "C" cross section. Binding the bronze coupling to the casing is a lock block composed of pearlite mixed with high temperature epoxy.

(1). Polyurethane Insulation—There are two specifications for polyurethane foam; one described in a letter from Cook dated 28 September, 1979 and the other contained in para. 2.4.1 on page 10 under "Hardware". It is not known which is being provided at this time. In neither case is there a temperature limitation indicated. Some preliminary computations using the insulation thicknesses shown on page 28 indicate that in many instances temperatures well above 300 degree F may be reached at the interface of the calcium silicate and polyurethane. At these temperatures the polyurethane will be destroyed resulting in loss of efficiency and exposing the casing to possible damage. The manufacturer should include in the brochure the upper limitation of the polyurethane being used and steady state calculations showing that this limitation will not be exceeded under varying pipe temperature and soil conductivity conditions.

(2). Annulus Rings—The EPDM annulus rings at the ends of the conduit sections are intended to limit the spread of leaks between adjoining units. It is important then that a tight seal be maintained at the heat carrying pipe at the casing. Para. 2.3 on page 10 under "Hardware" indicates very significant changes in physical characteristics when the material is subjected to aging for only 240 hours at 300 °F. Changes of around 60 percent in tensile strength, elongation at rupture, and urometer hardness suggest rapid deterioration of the material. Since the ring will be in direct contact with the heat carrying pipe, test should be performed at 450 °F. for an extended period and the contact surface carefully checked to see whether a seal can be maintained.

(3). Conduit and Coupling Casing—The casing is a reinforced thermosetting resin plastic (RTRP) using a polyester isothalic resin. The only data regarding physical properties is contained in para. 2.6, page 11 where tensile and compressive strengths are shown at 75 and 200 °F. These indicate a radical decrease strength at higher temperatures. The manufacturer should provide steady state calculations to establish casing temperatures at maximum operating temperatures and variable soil conditions. Based on coupling dimensions shown in the table in para. 1.11.1 on page 24 under "Hardware", there will be a 1 to 2 inch annular air space on each side of the coupling where the casing will be exposed directly to heat transfer from the hot piping. Casing temperatures at those points should also be established. Since casing failures have often been found on systems using RTRP casings after a few years of operation, it is important that acceptable aging test data be provided for this element of the system.

(4). Secondary Joint Sealing Ring—Letters from Seals Eastern, Inc. indicate that two HTRC formulations were available for this system element. One was suitable for operation at 300 °F. and the other at 400 °F. Para. 2.1 on page 9 under "Hardware" does not state which is being provide and what other material is available for temperatures exceeding 400 °F. These matters should be clarified and acceptable aging tests should be provided to insure proper long term operation.

(5). Lock Block—The lock block which holds the bronze coupling in the casing consists of a composite of pearlite mixed with high temperature epoxy. The only description of this material is shown on page 11, para. 2.5 which indicates a "k" factor of 1.0 at 300 °F. Casing Temperatures at the coupling should be computed based on this "k" factor. Recent field inspections have shown very severe corrosion of the bronze coupling at its interface with the epoxy material. A chemical analysis of the epoxy together with an indication of its stability at temperatures up to 450 °F. should be provided in order to establish compatibility with the bronze coupling.

(6). Silicon Lubricant—It is apparent from thee italicized warning contained on page 41, that the type of lubricant is of some significance in the construction and possibly the operation of the system. Physical and chemical characteristics of the material should therefore be provided.

b. <u>Condensate Line Conduits.</u> The two condensate line conduits "Sch 80 Heat-Tite" and "RTRP Vee-Tite" are similar in design and construction except for the heat carrying piping. As indicated in their nomenclature, schedule 80 steel pipe is provided for "Sch 80 Heat-Tite" conduit and reinforced plastic pipe is used in the "RTRP Vee-Tite" system. Conduits are provided in 20 foot sections and utilize polyurethane insulation with a PVC jacket. These materials are in accord with Corps of Engineers guide specifications CEGS-02698 "Prefabricated Underground Heating/Cooling Distribution System" and are therefore considered satisfactory for this application.

(1). Coupling Dimensions—Dimensions for ductile iron and RTRP couplings are not provided as was done for Super Temp-Tite on page 24.

(2). Carrier Sealing Ring—On page 13, sealing rings are specified to be molded, heat resistant EPDM. On page 47, these rings are designated as "Heat-Tite R.T." and "HTHR" in paragraphs 8.5.1 and 8.5.2. Clarification is required.

(3). Steel Pipe Spigot Ends—For Super Temp-Tite, spigot ends are required to be metallized with nickel alloy then machined back to the required O.D. with a maximum rms of 32

(page 12). For the steel condensate pipe, the spigot ends are sand blasted to white metal and zinc coated (para. 4.1.1, page 14). The method of application of the zinc should be described and an indication that the finish is adequate to provide a tight seal is required.

(4). Silicone Caulking—End of para. 9.8, page 52 permits the use of silicon caulking in lieu of EPDM end seal. Method of application, physical, and aging characteristics for this material should be provided.

General Recommendations

a. Testing Requirements. An in-depth field inspection survey of TPS systems is currently being done by the Cold Regions Research and Engineering Laboratory. The results of that survey should verify or dispel concerns regarding the suitability of the materials furnished such as, conduit end seals, pipe sealing rings, conduit casing, polyurethane foam, and epoxy. Any new aging tests proposed by the manufacturer should be reviewed in detail by the government to insure that procedures and resulting data will be acceptable. Actual testing should not be done by the material manufacturer but should be performed by an approved independent testing laboratory. All test data should be directly available to the government for review and analysis.

b. Maintenance and Repair. The repair sections for the TPS conduits are very difficult to follow and are somewhat confusing. Foe example, the dimensions shown on the diagram on page 64 appear to be for 10 foot pipe sections rather than for the standard 20 foot lengths. Also, repairs include the use of epoxy adhesive and compression couplings for which no descriptive details are provided. Recommend that this entire section be rewritten and augmented with clarifying sketches at each step of the repair procedure.

Appendix B: Temperature Distribution Profiles for Different Carrier Pipe Diameters, Soil Conductivities, and Temperatures

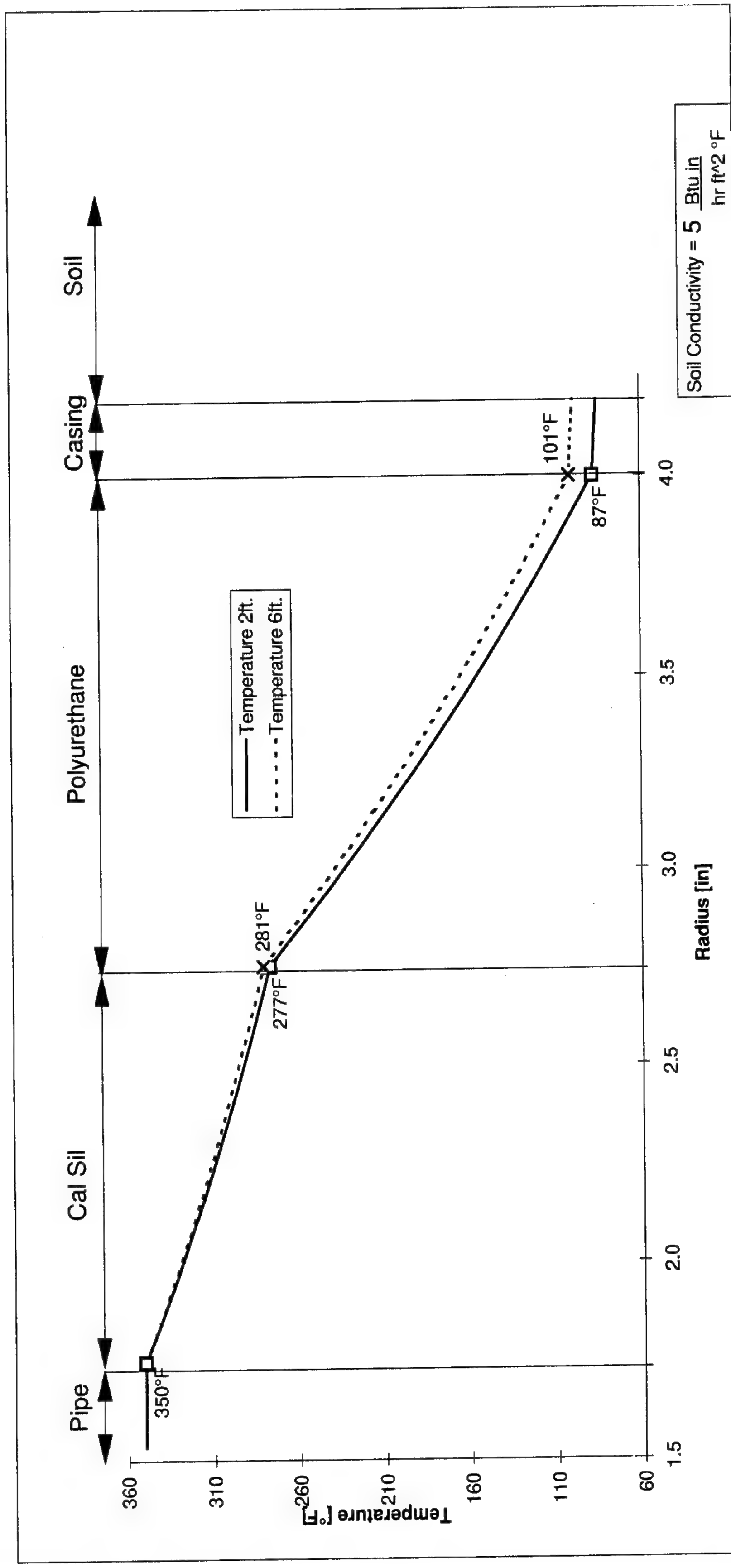

Figure B.1. 3 in. pipe at 350 °F (soil conductivity = 5).

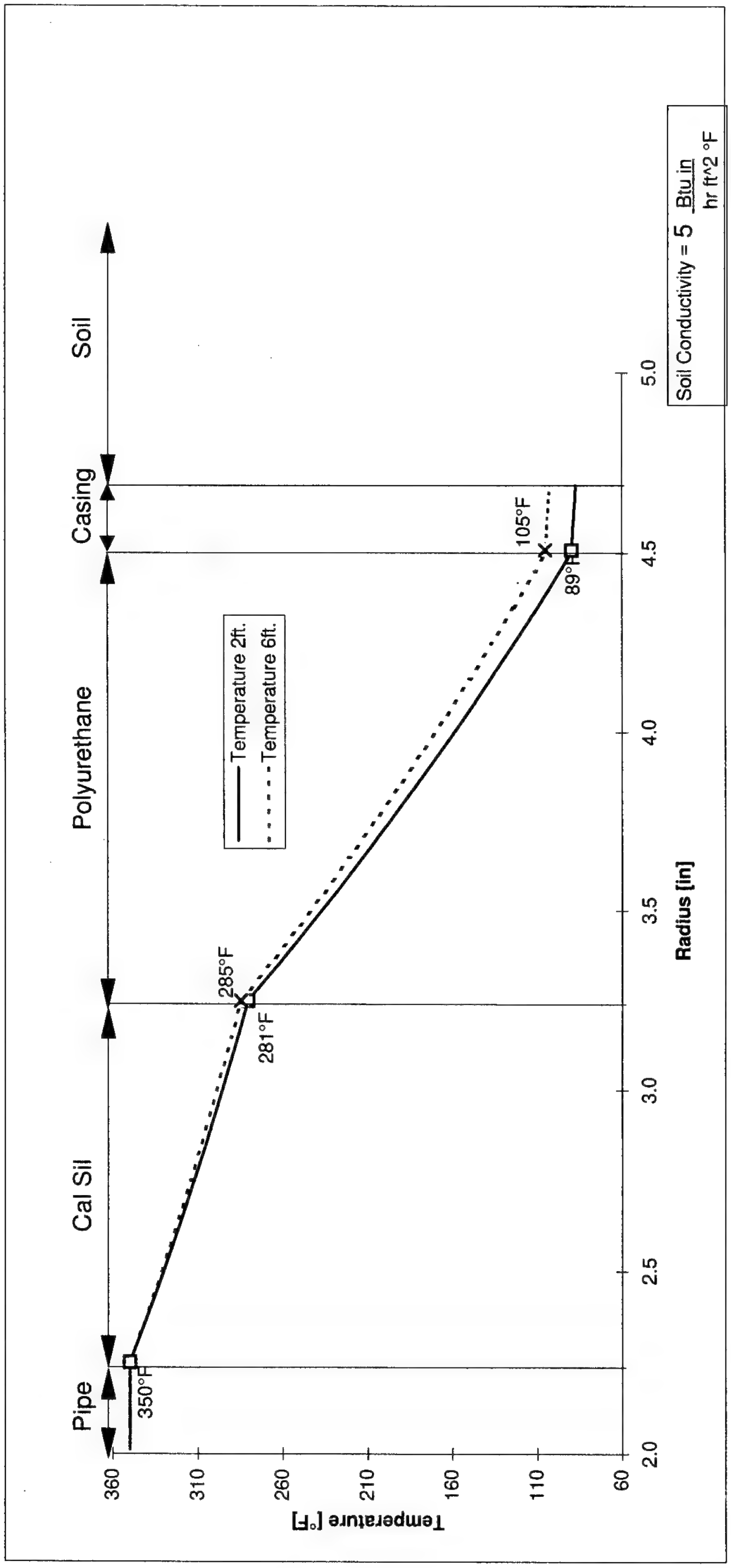

Figure B.2. 4 in. pipe at 350 °F (soil conductivity = 5).

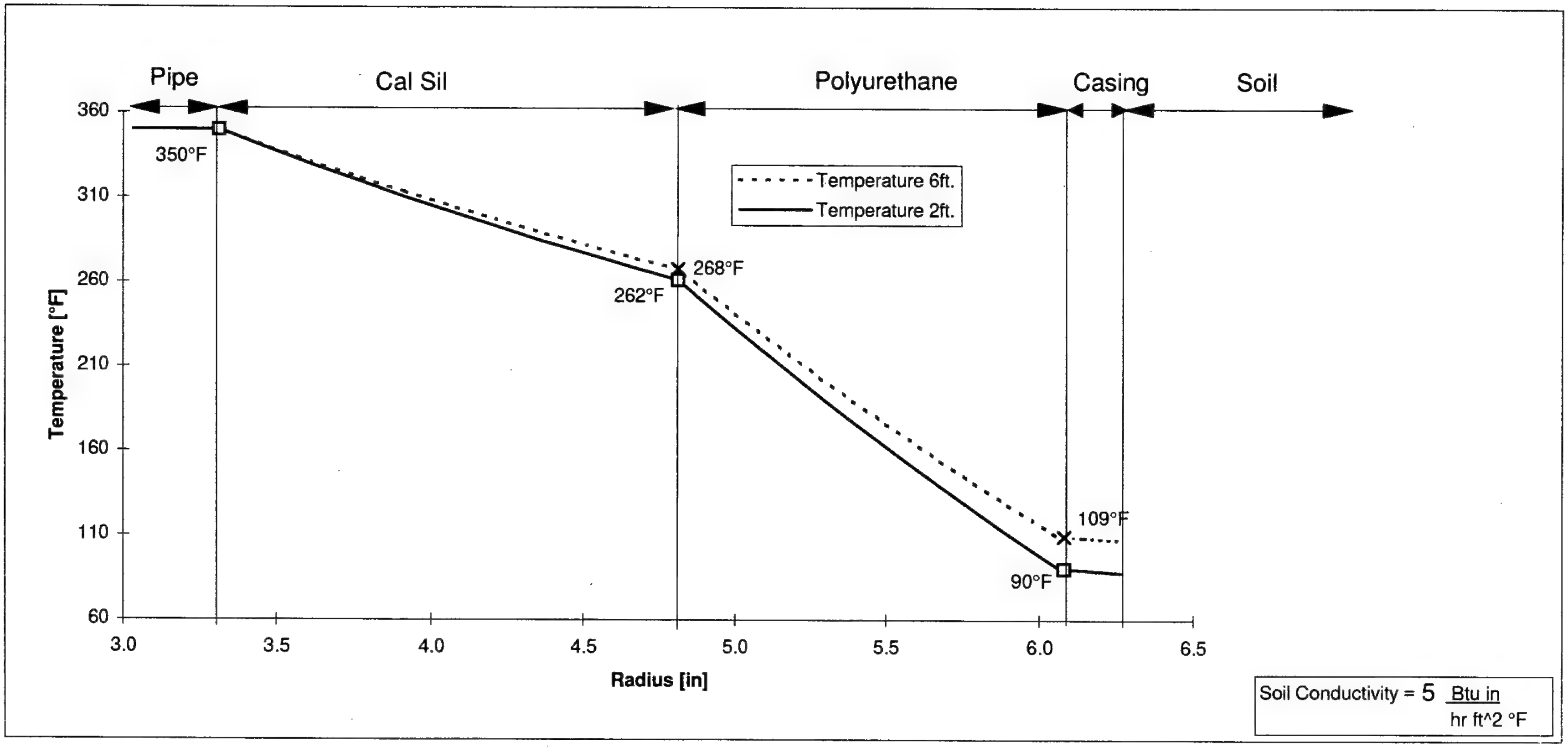

Figure B.3. 6 in. pipe at 350 °F (soil conductivity = 5).

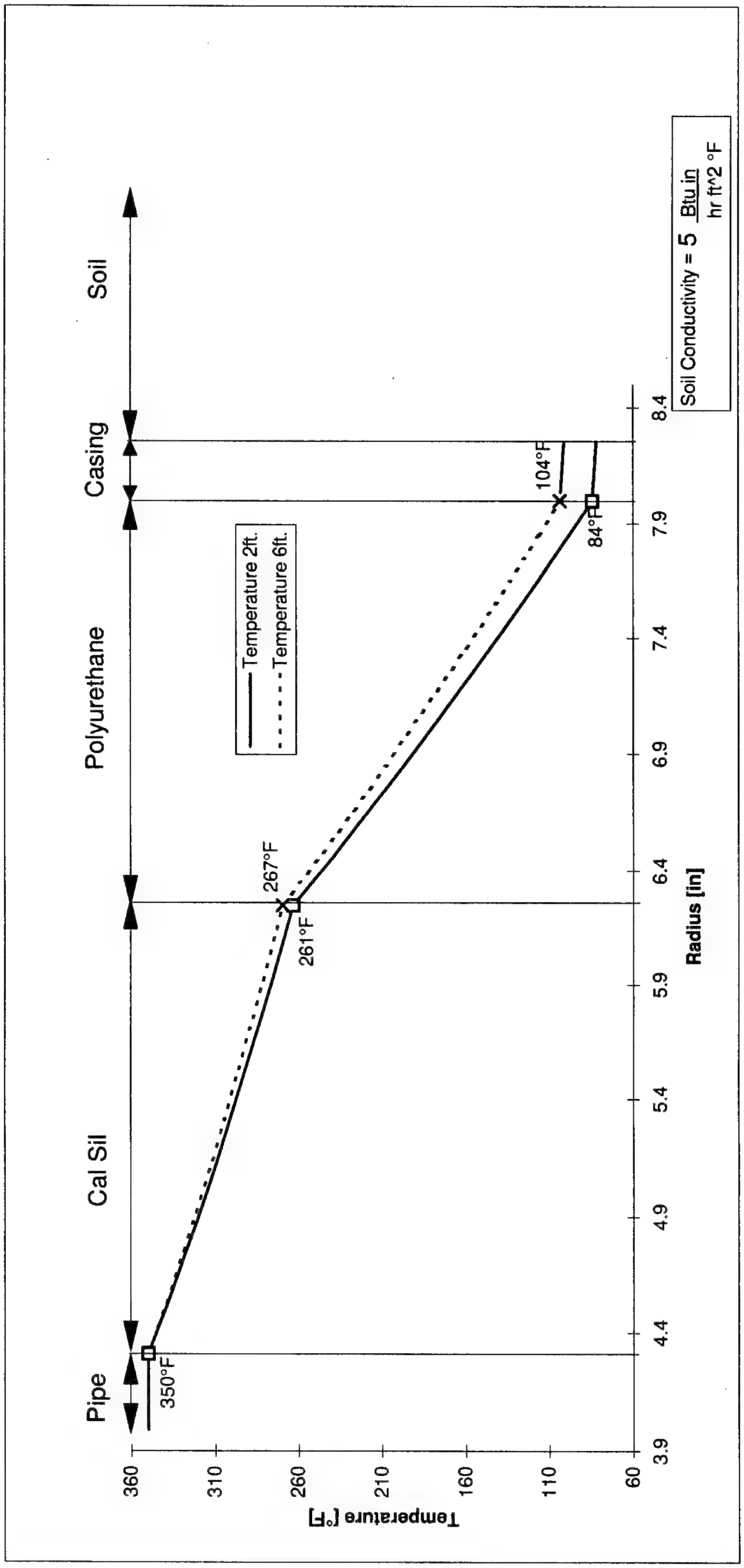

Figure B.4. 8 in. pipe at 350 °F (soil conductivity = 5).

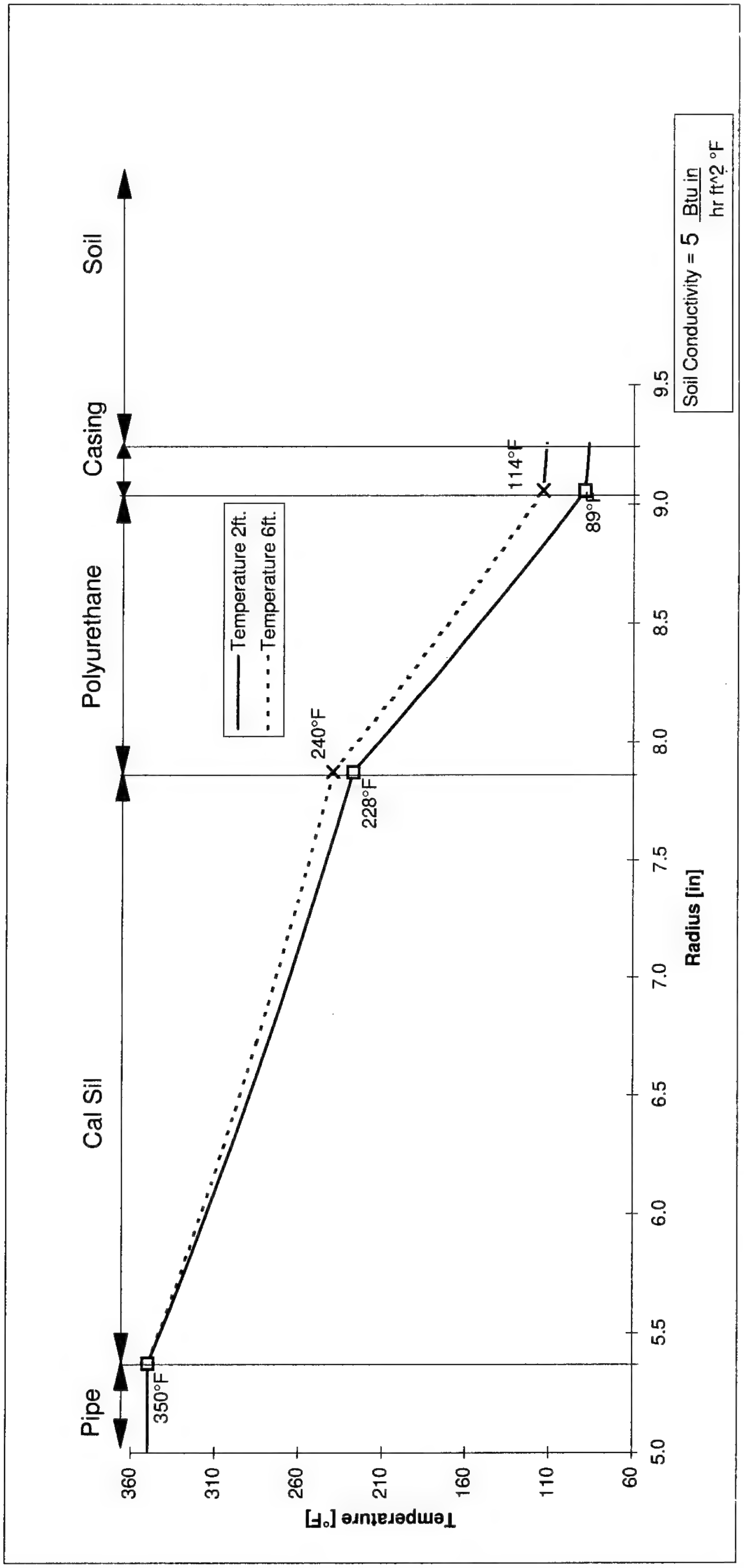

Figure B.5. 10 in. pipe at 350 °F (soil conductivity = 5).

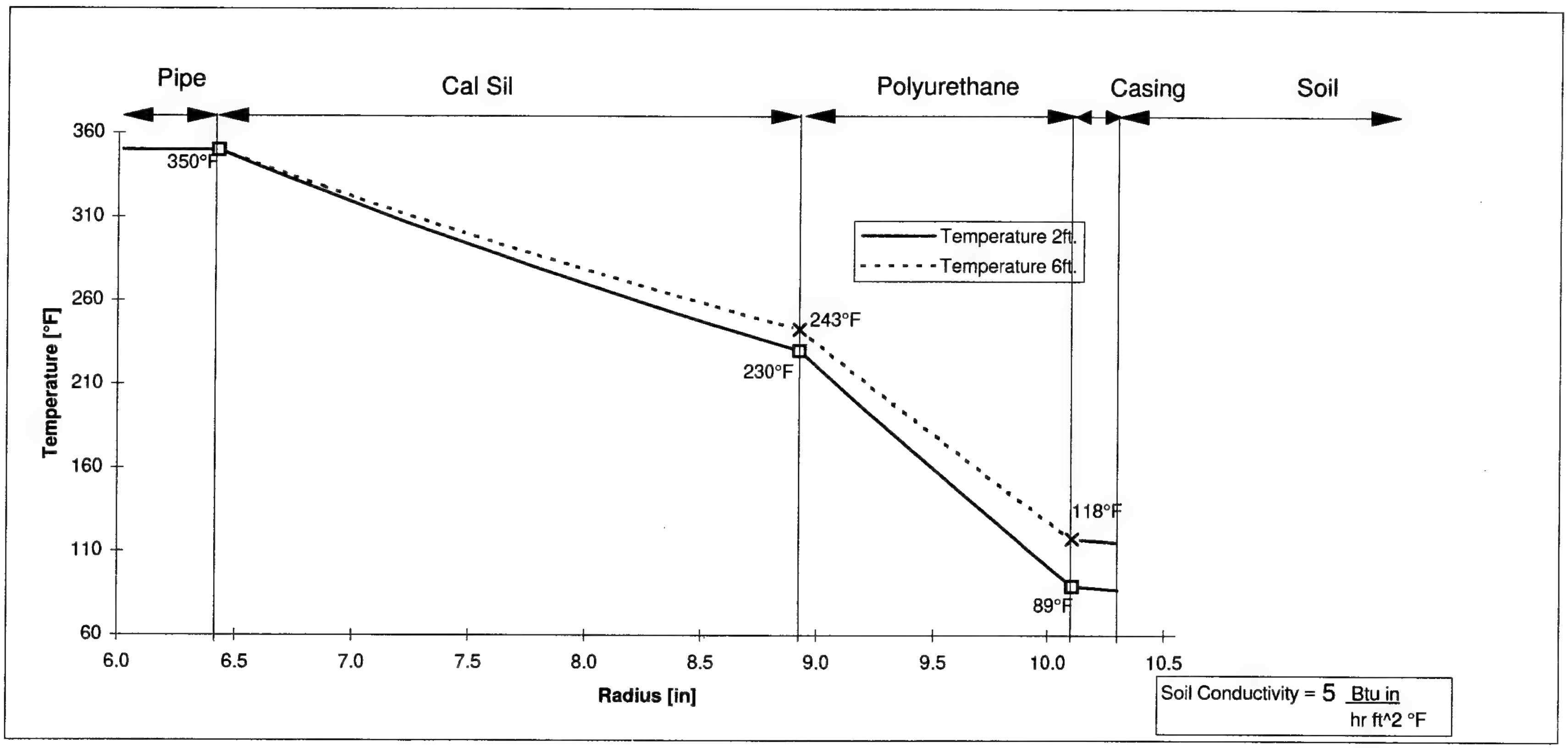

Figure B.6. 12 in. pipe at 350 °F (soil conductivity = 5).

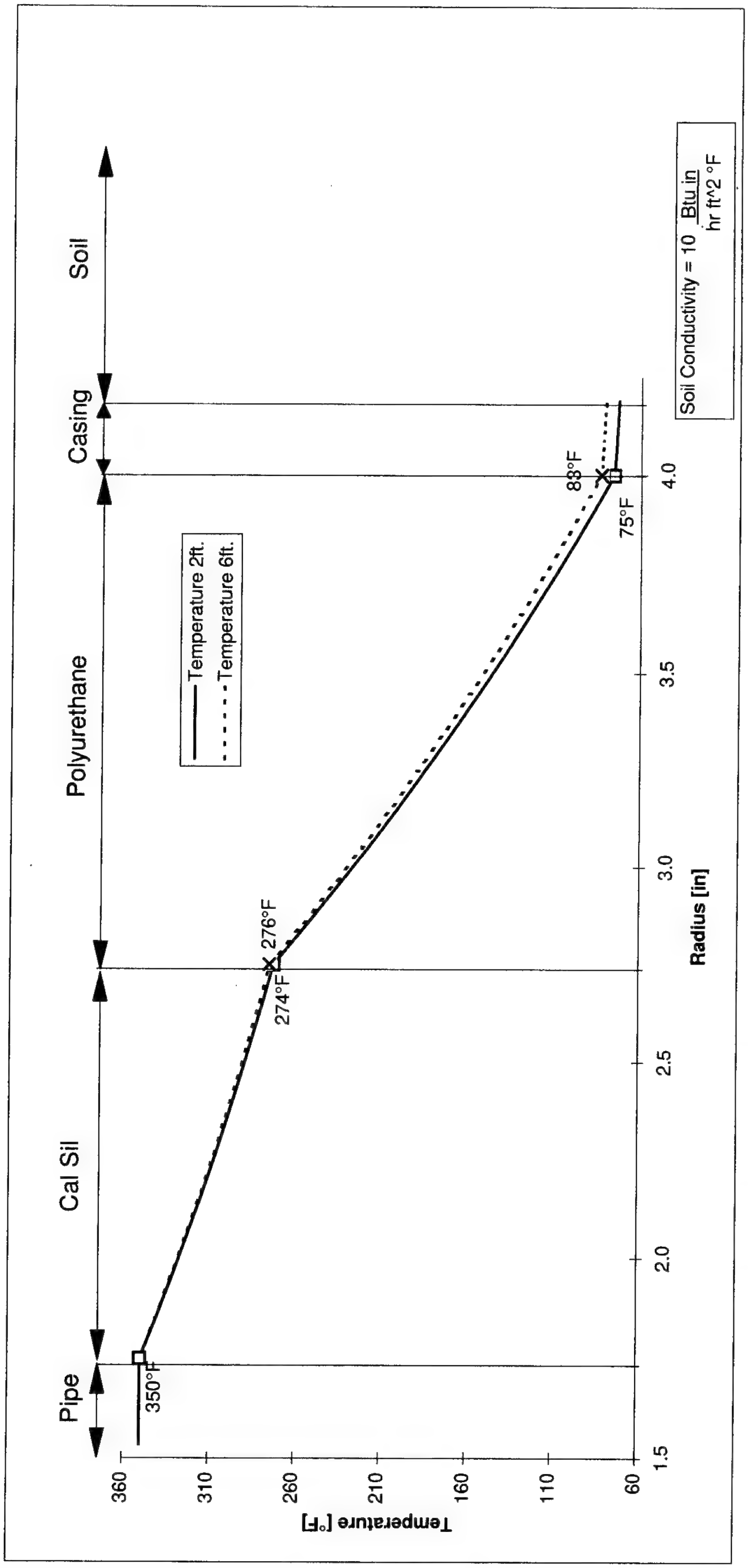

Figure B.7. 3 in. pipe at 350 °F (soil conductivity = 10).

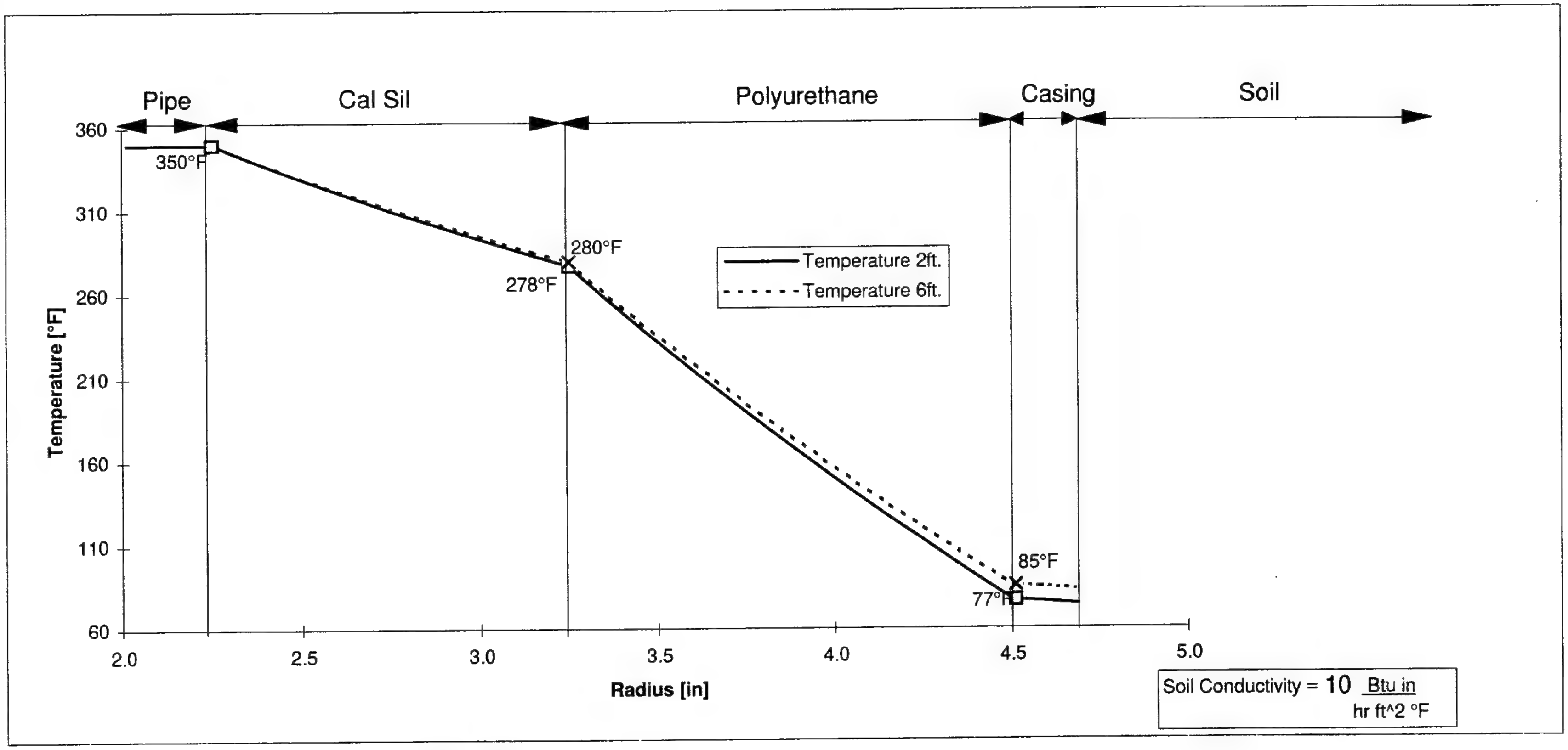

Figure B.8. 4 in. pipe at 350 °F (soil conductivity = 10).

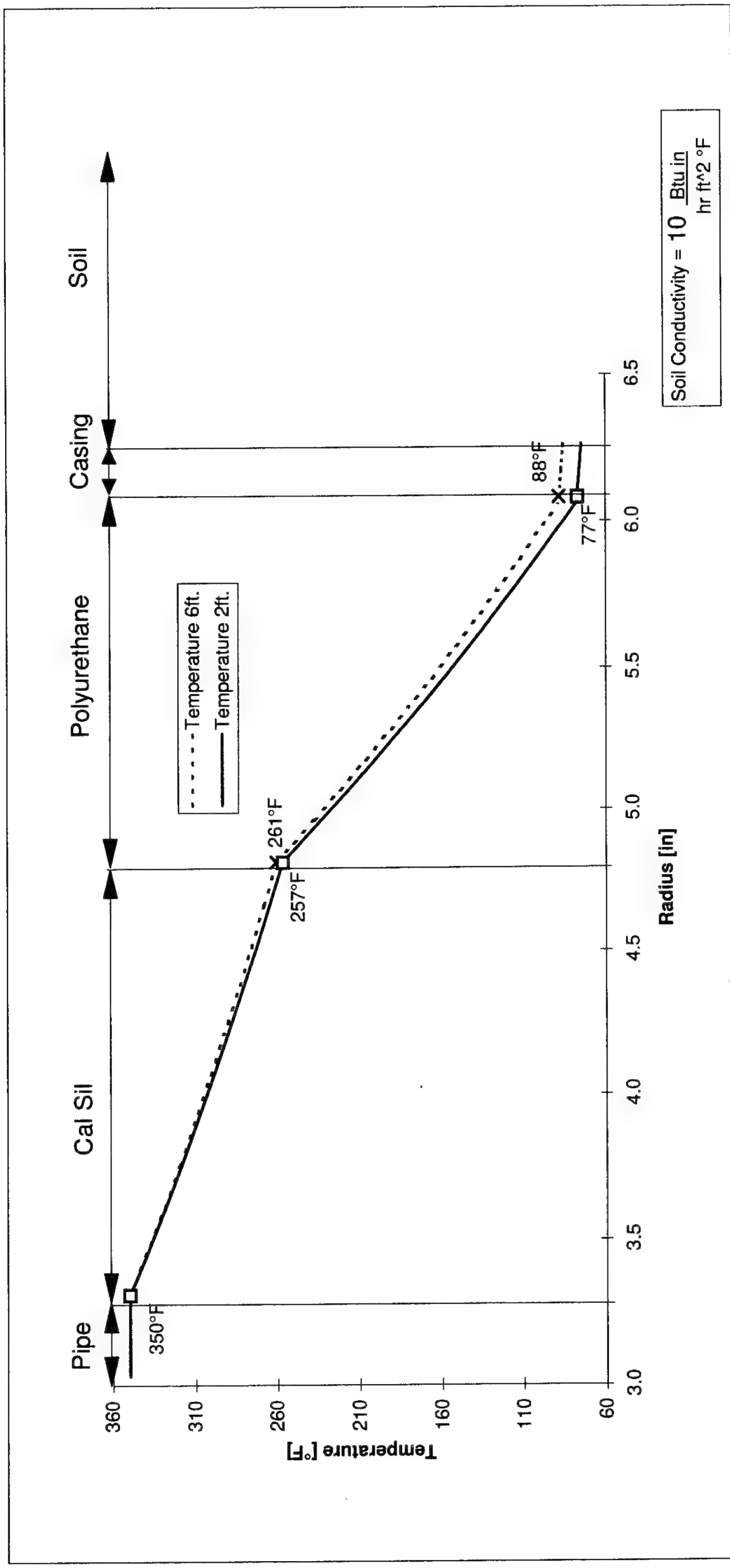

Figure B.9. 6 in. pipe at 350 °F (soil conductivity = 10).

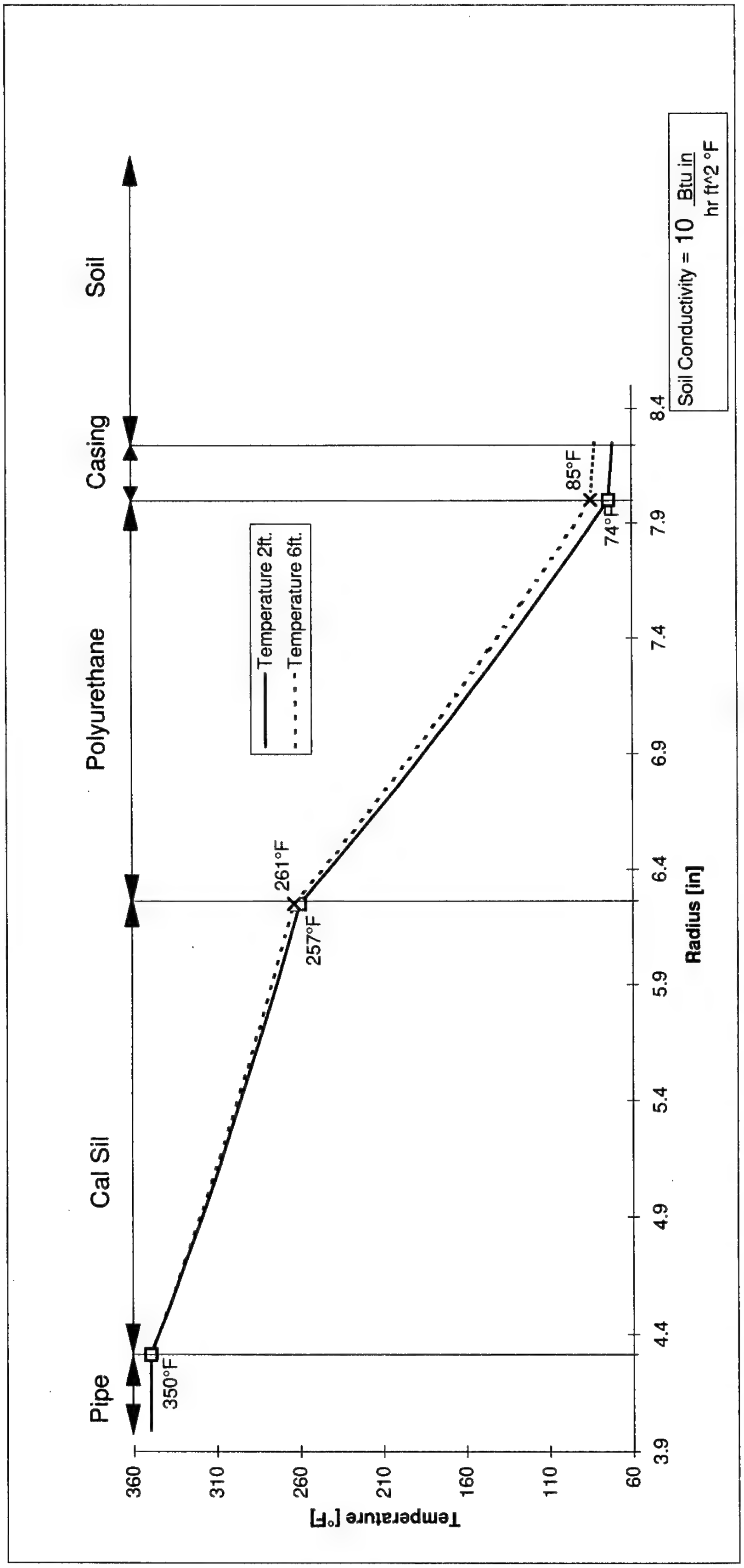

Figure B.10. 8 in. pipe at 350 °F (soil conductivity = 10).

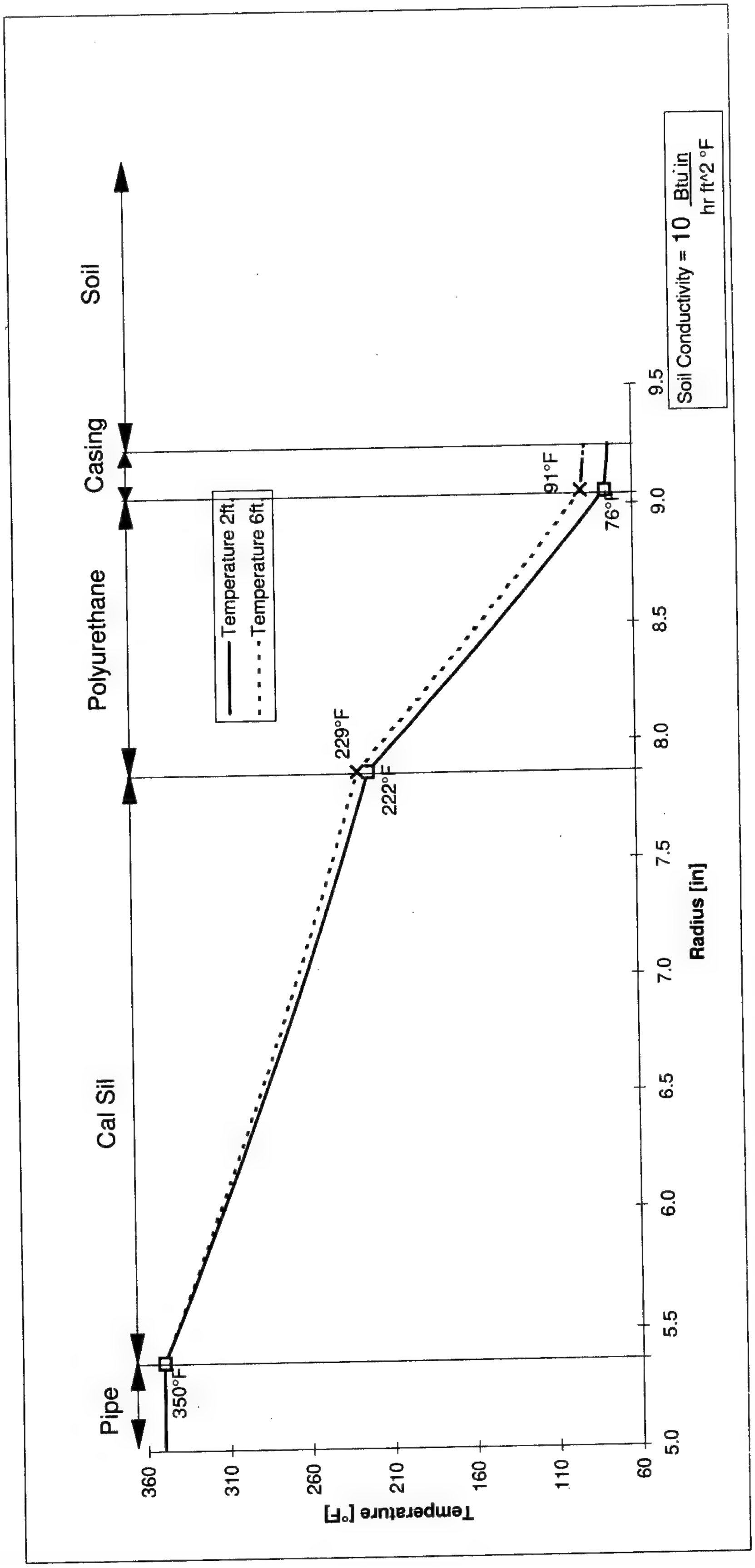

Figure B.11. 10 in. pipe at 350 °F (soil conductivity = 10).

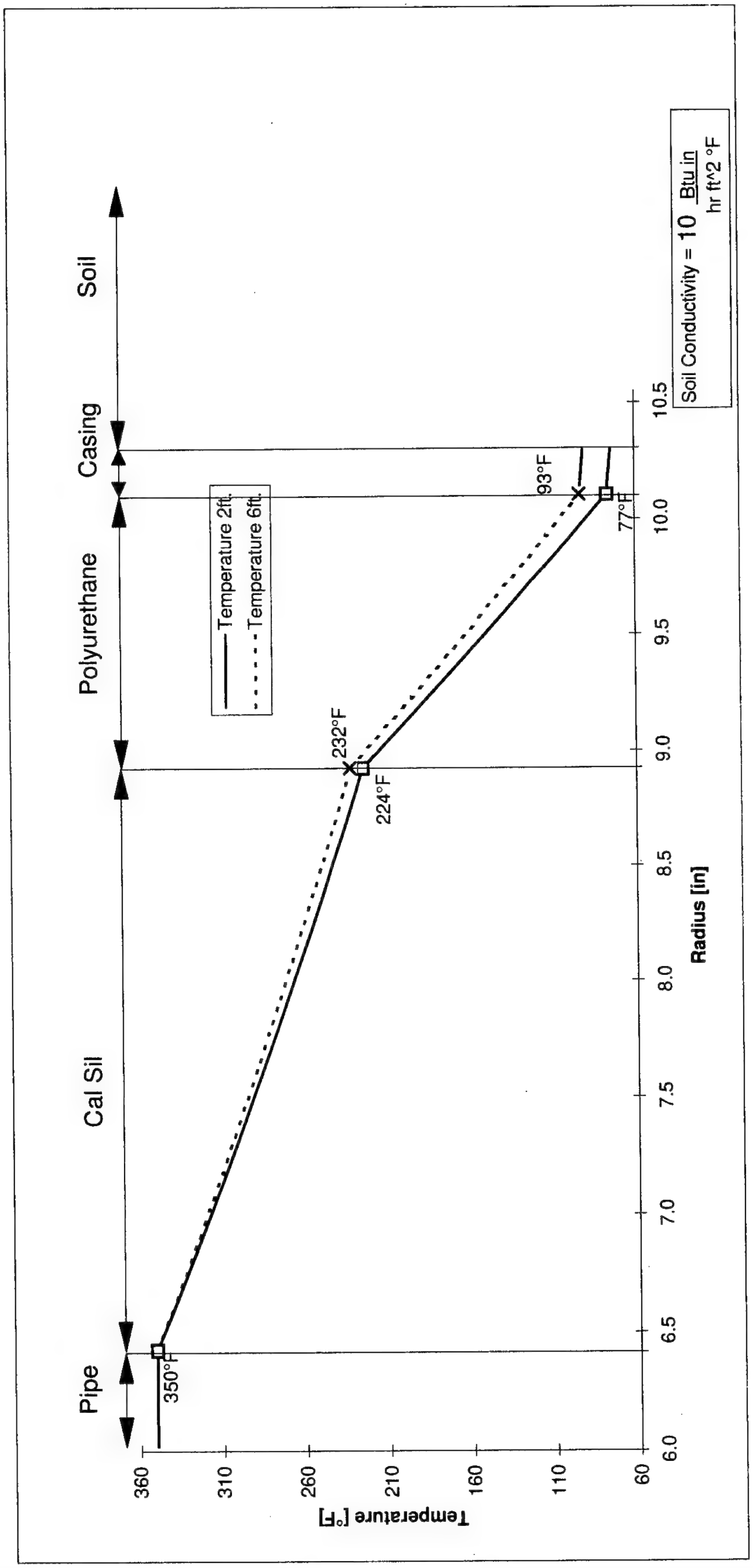

Figure B.12. 12 in. pipe at 350 °F (soil conductivity = 10).

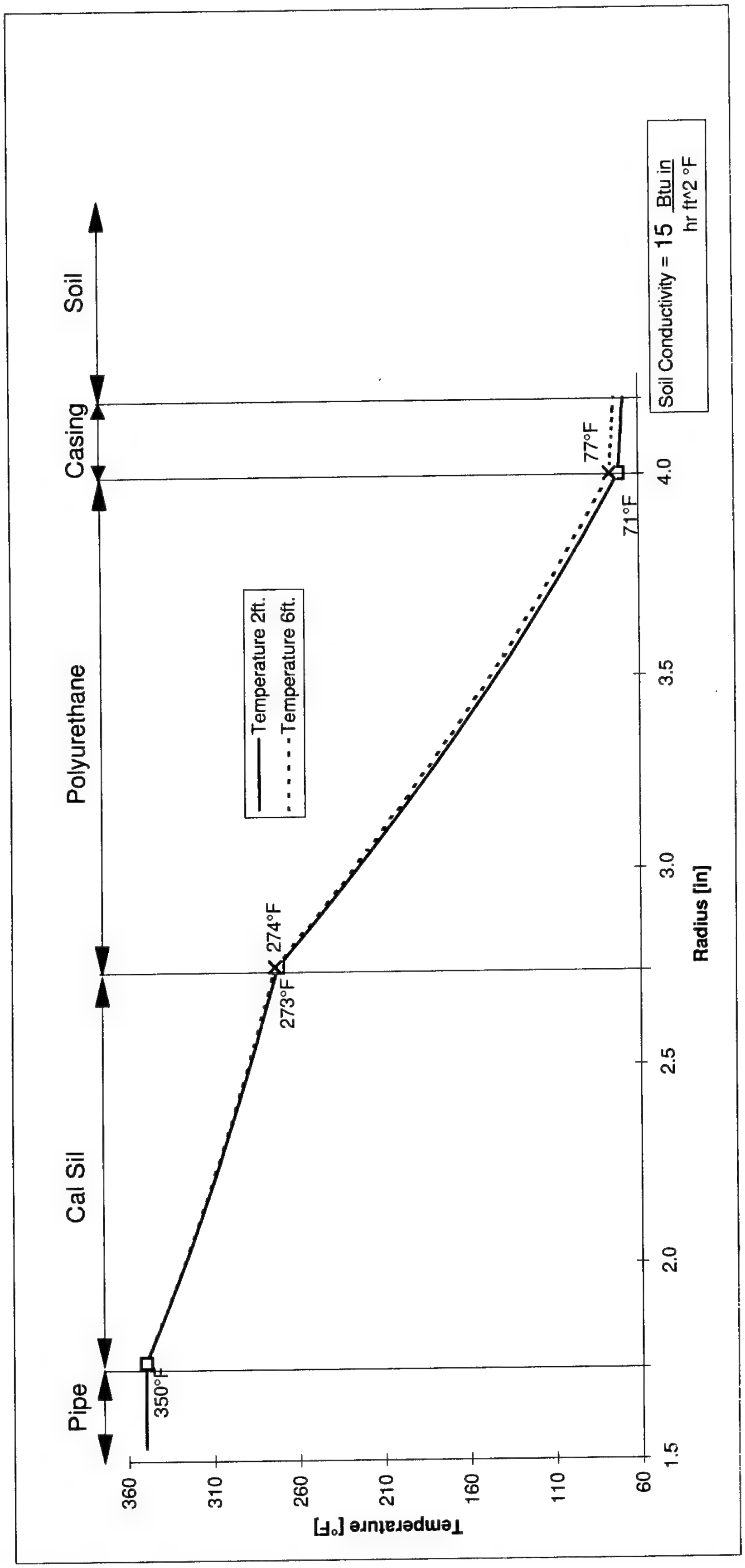

Figure B.13. 3 in. pipe at 350 °F (soil conductivity = 15).

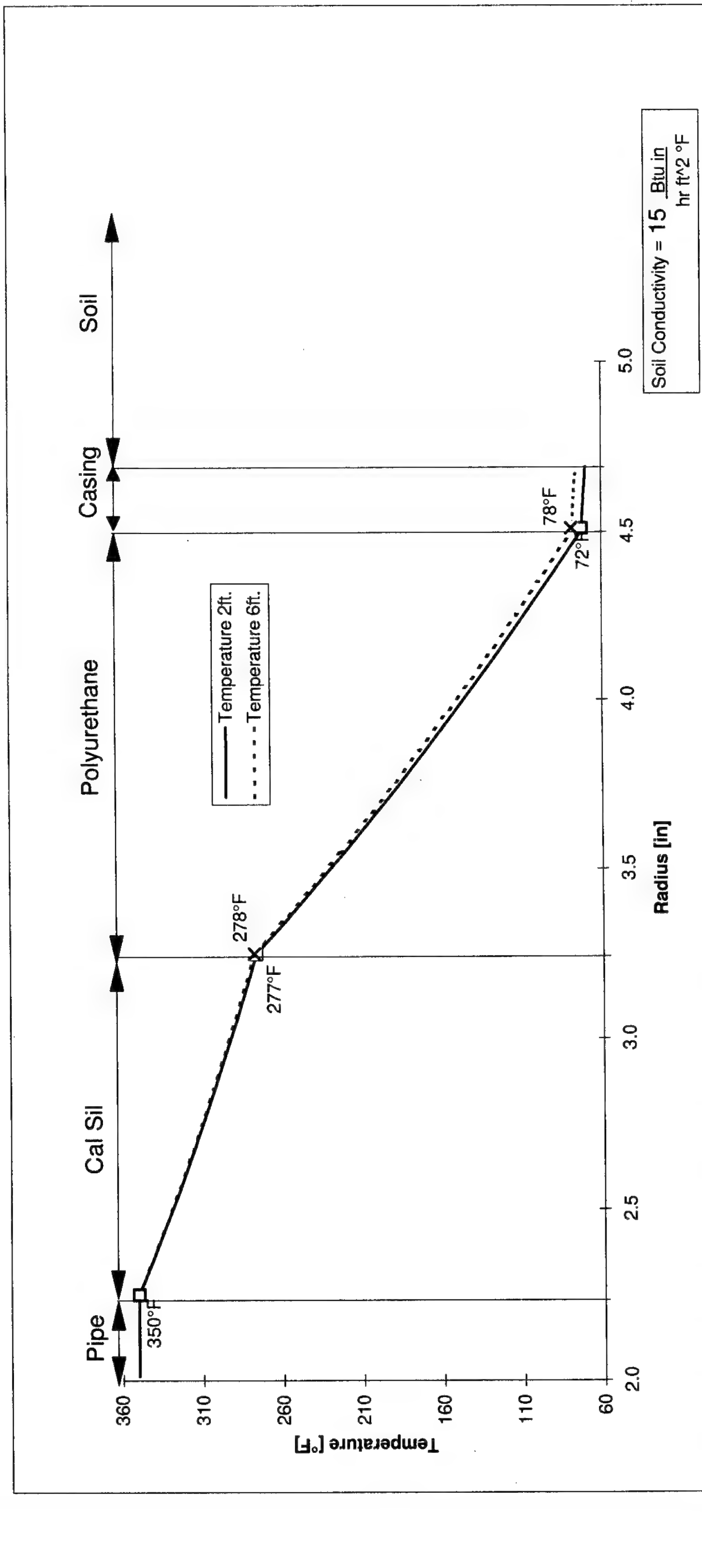

Figure B.14. 4 in. pipe at 350 °F (soil conductivity = 15).

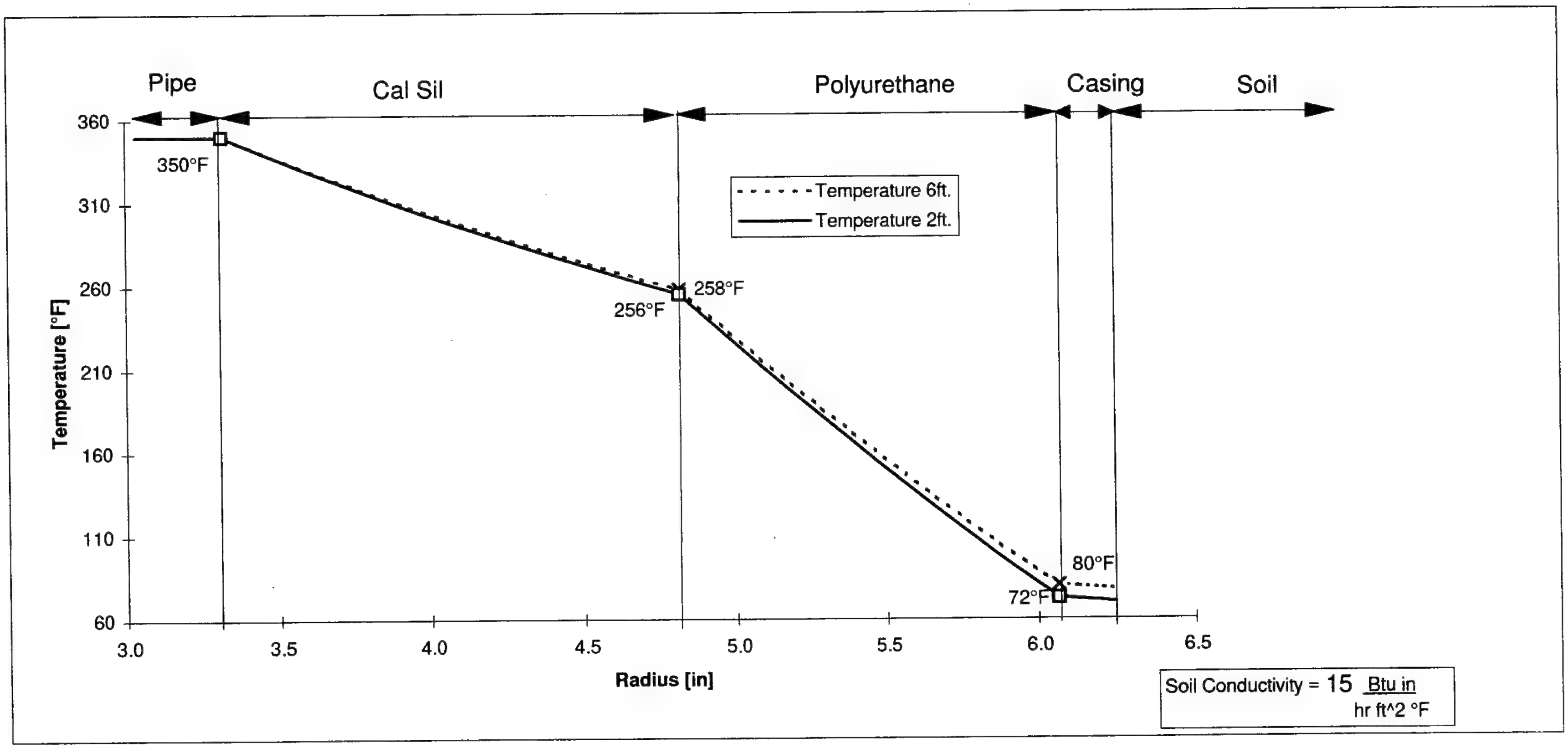

Figure B.15. 6 in. pipe at 350 °F (soil conductivity = 15).

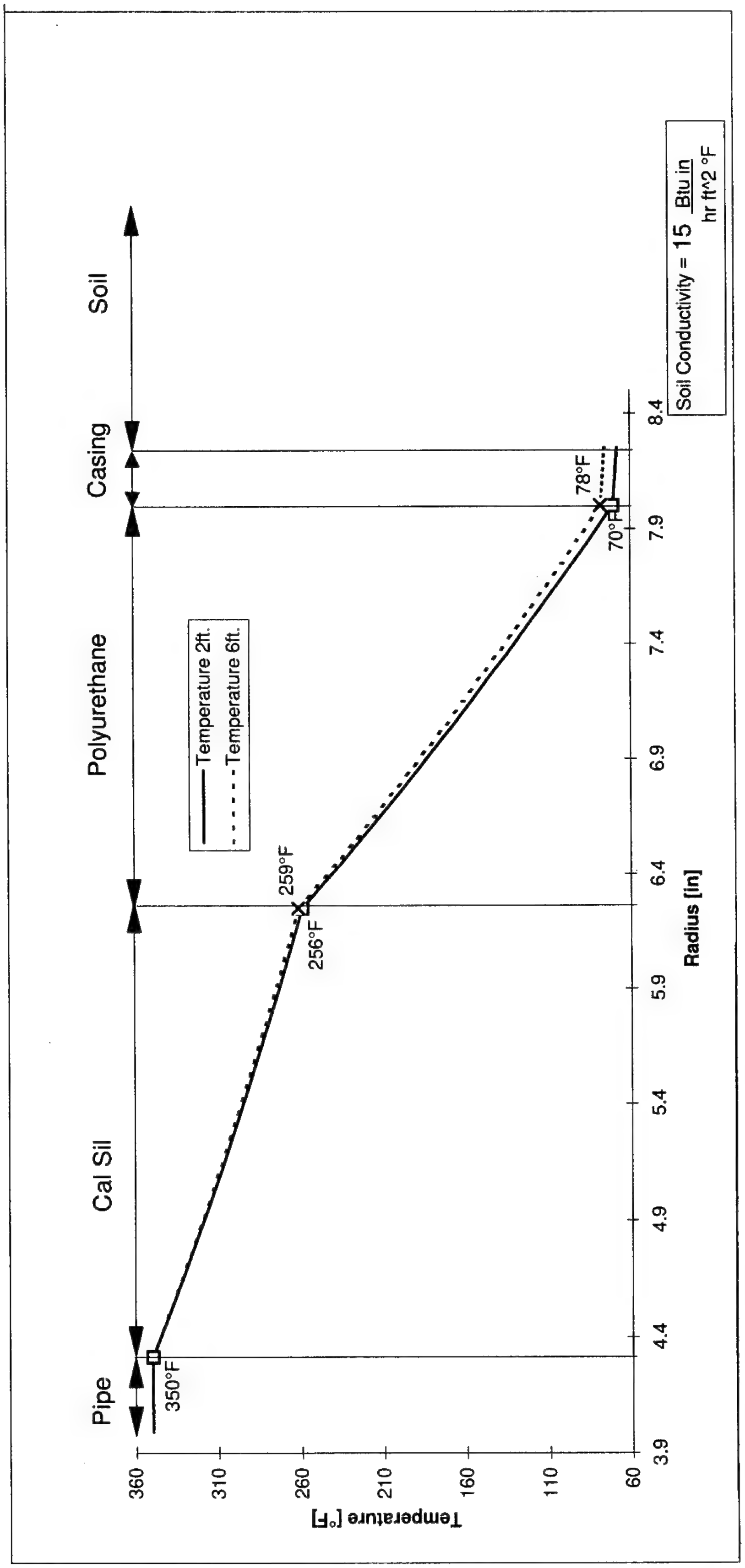

Figure B.16. 8 in. pipe at 350 °F (soil conductivity = 15).

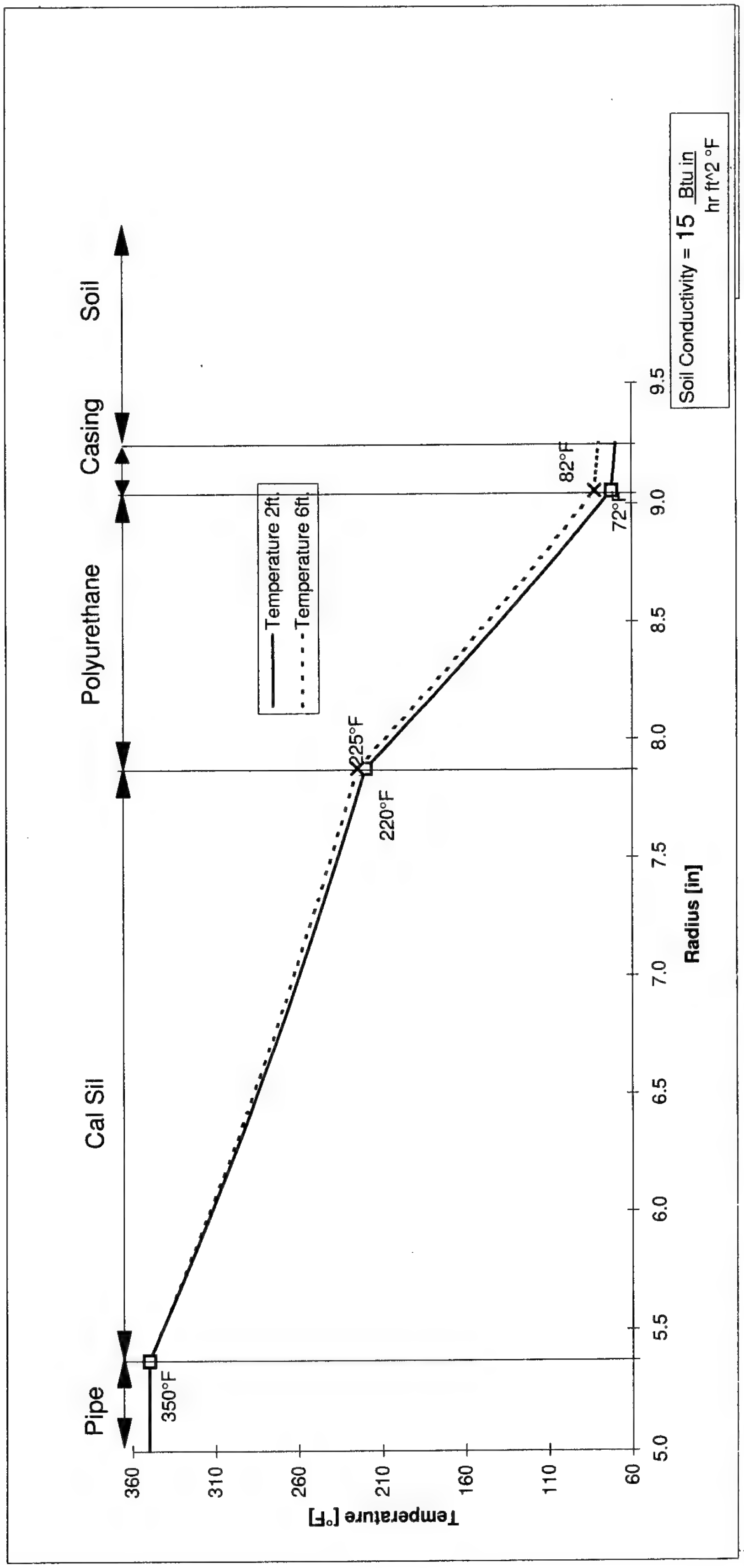

Figure B.17. 10 in. pipe at 350 °F (soil conductivity = 15).

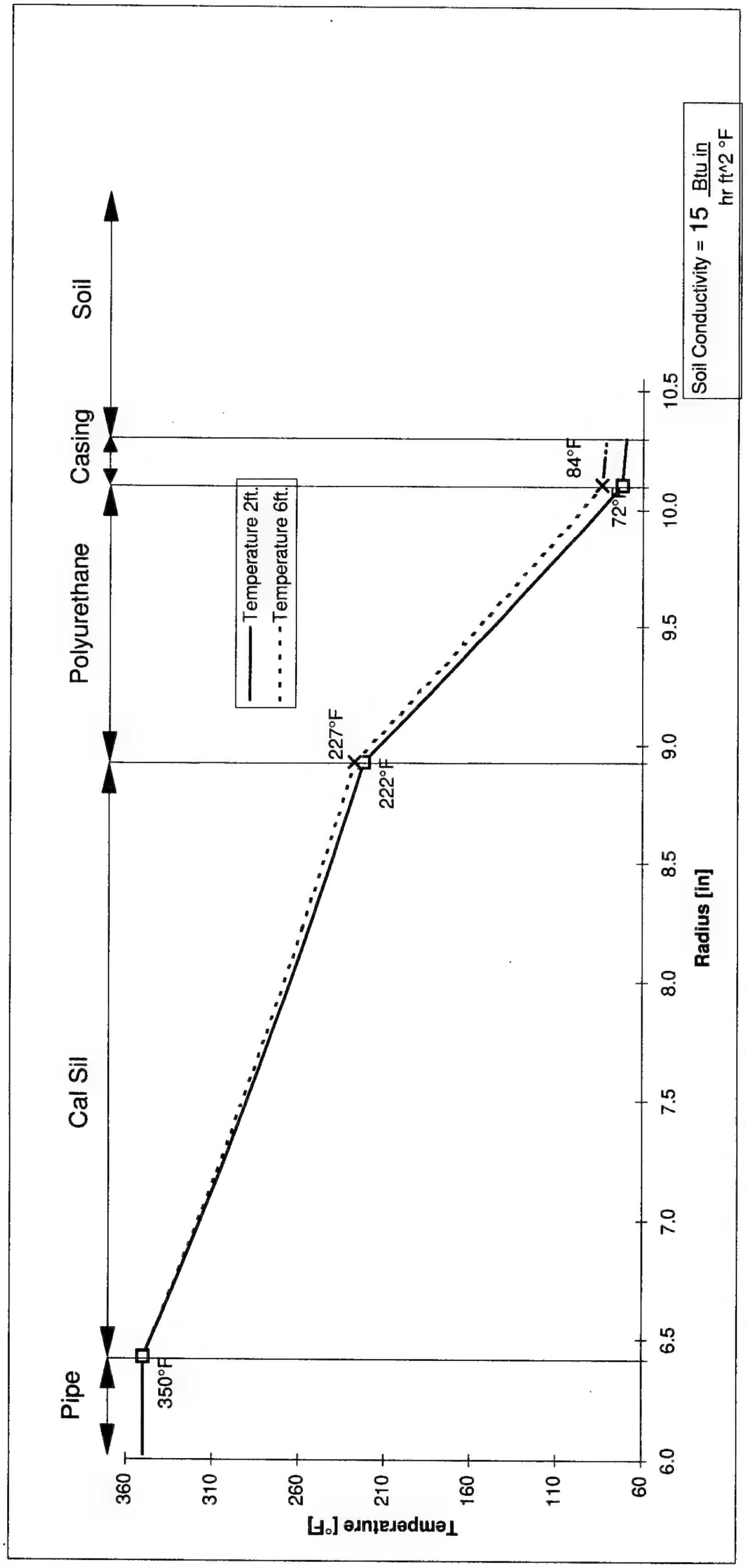

Figure B.18. 12 in. pipe at 350 °F (soil conductivity = 15).

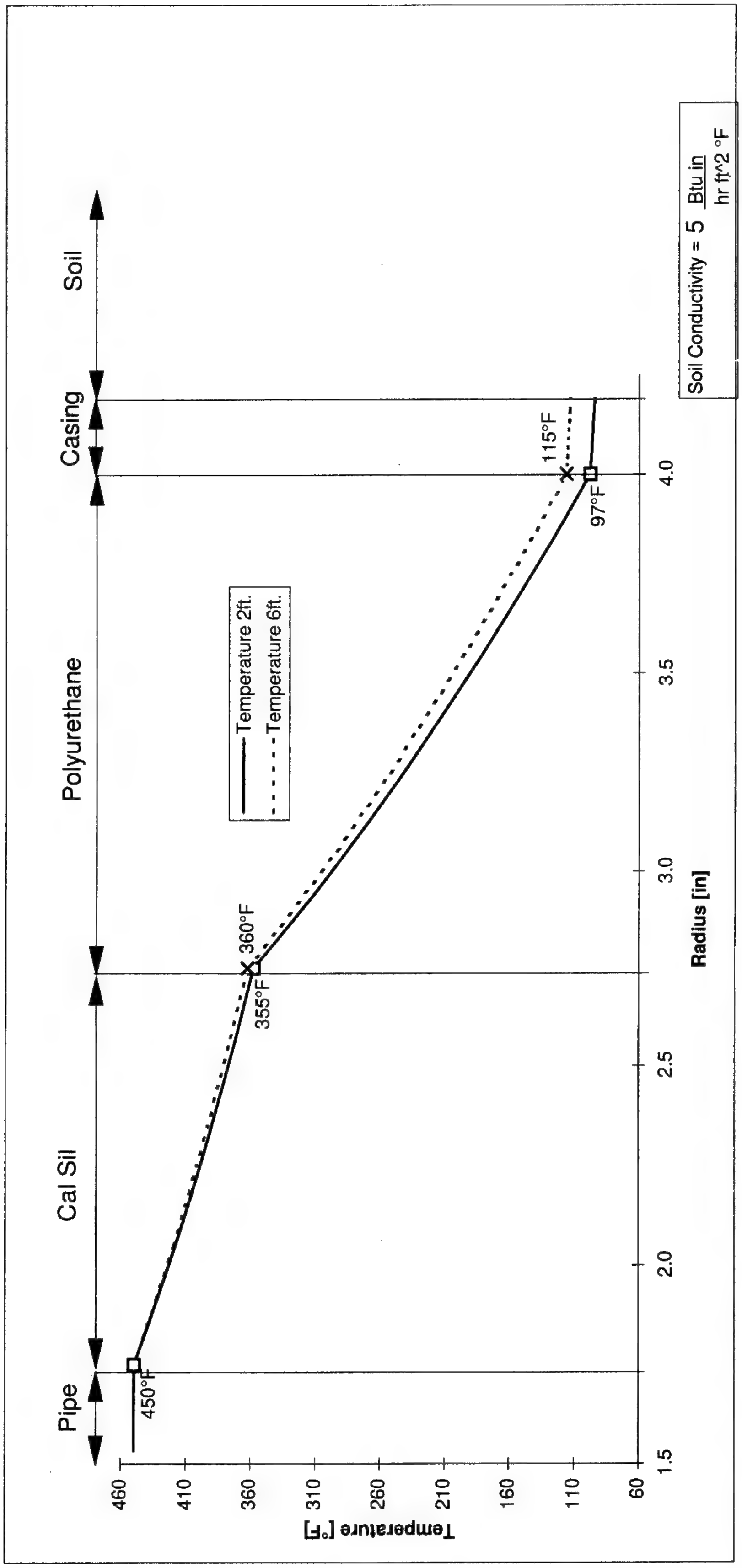

Figure B.19. 3 in. pipe at 450 °F (soil conductivity = 5).

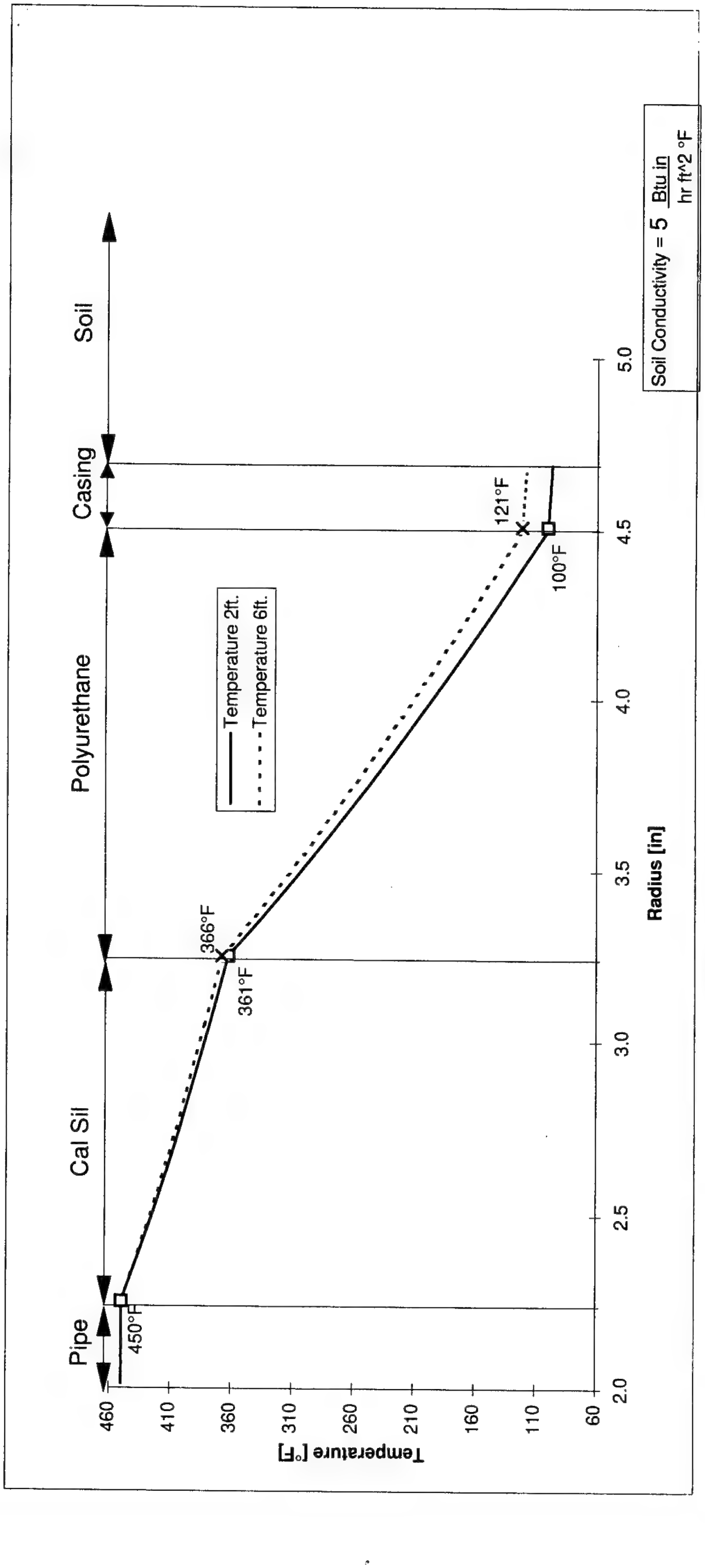

Figure B.20. 4 in. pipe at 450 °F (soil conductivity = 5).

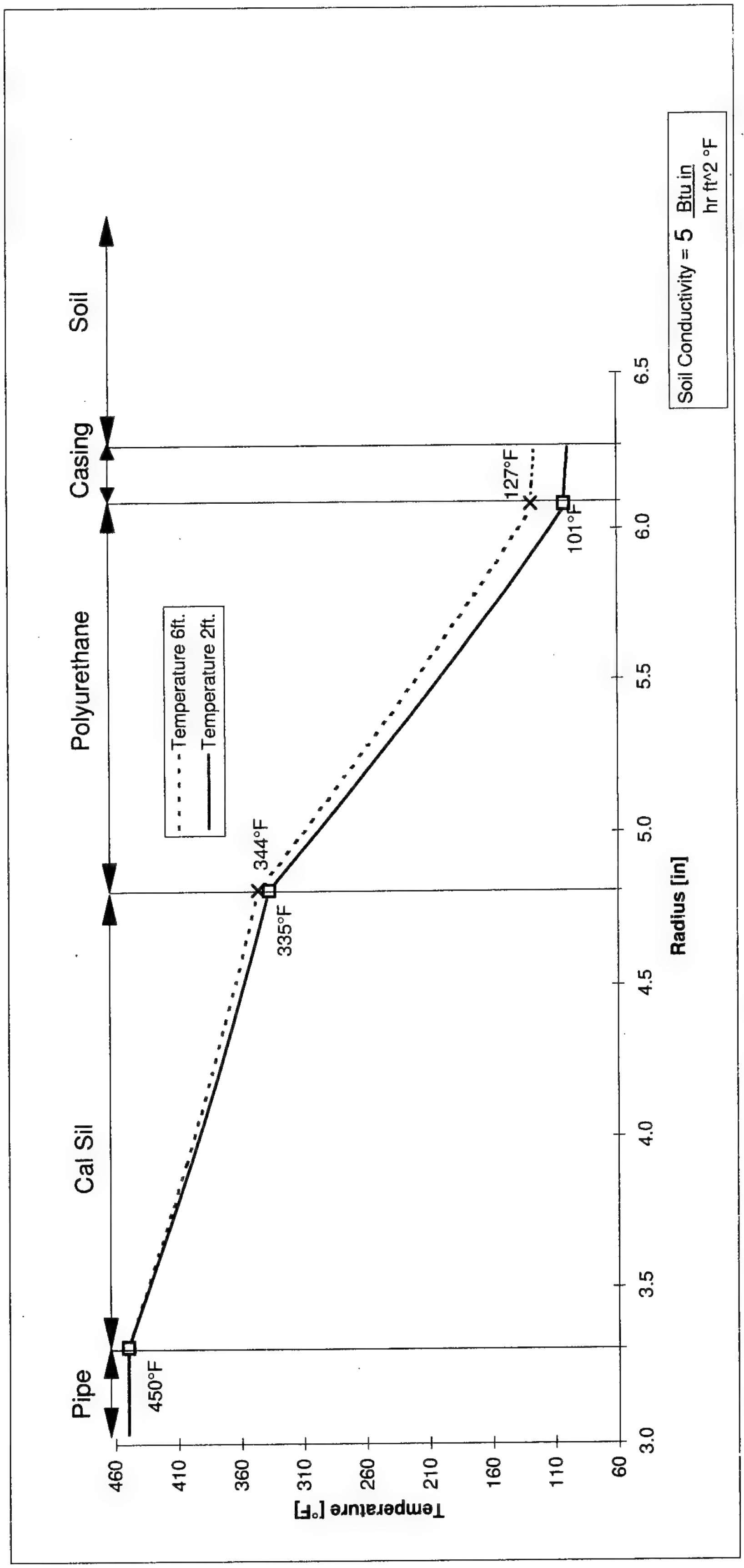

Figure B.21. 6 in. pipe at 450 °F (soil conductivity = 5).

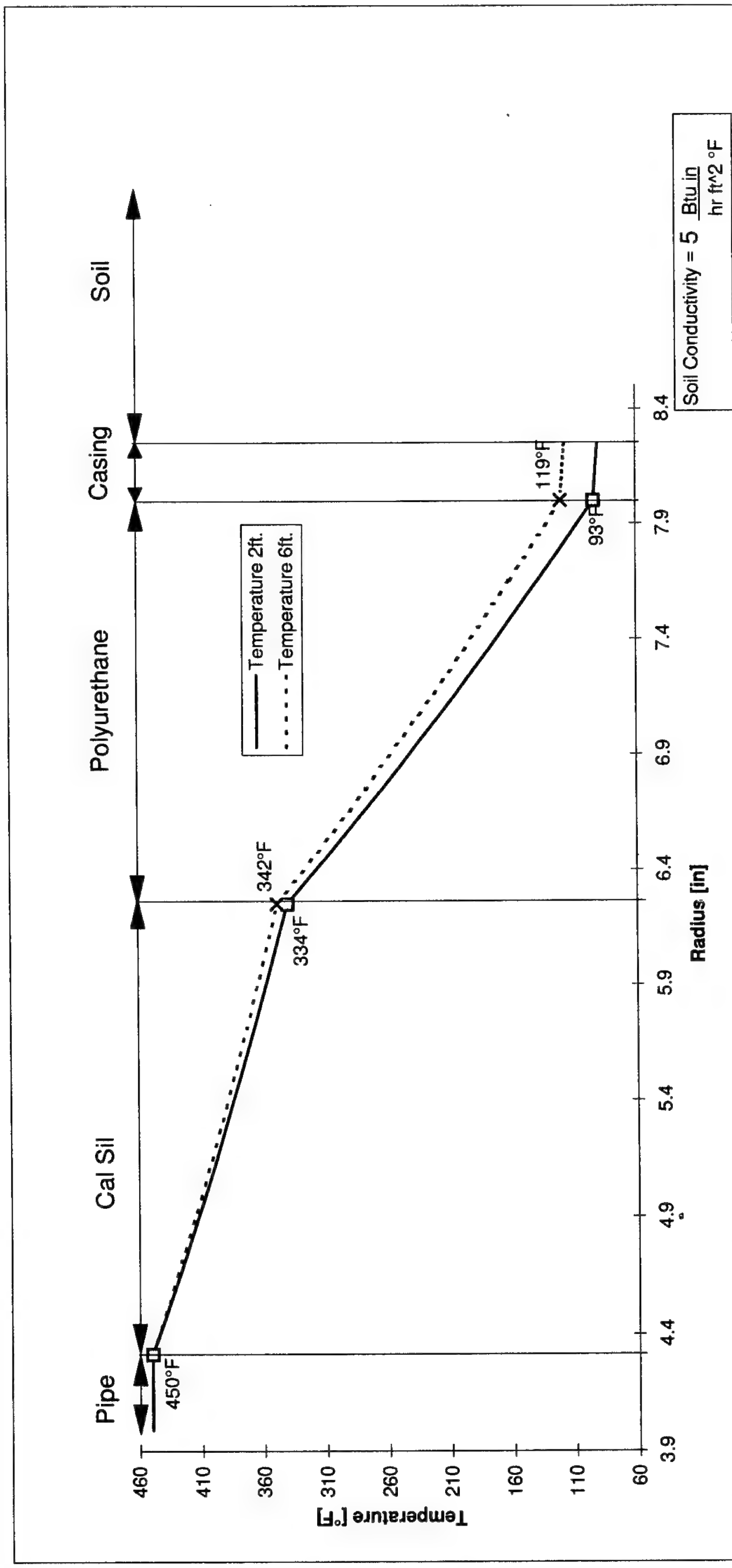

Figure B.22. 8 in. pipe at 450 °F (soil conductivity = 5).

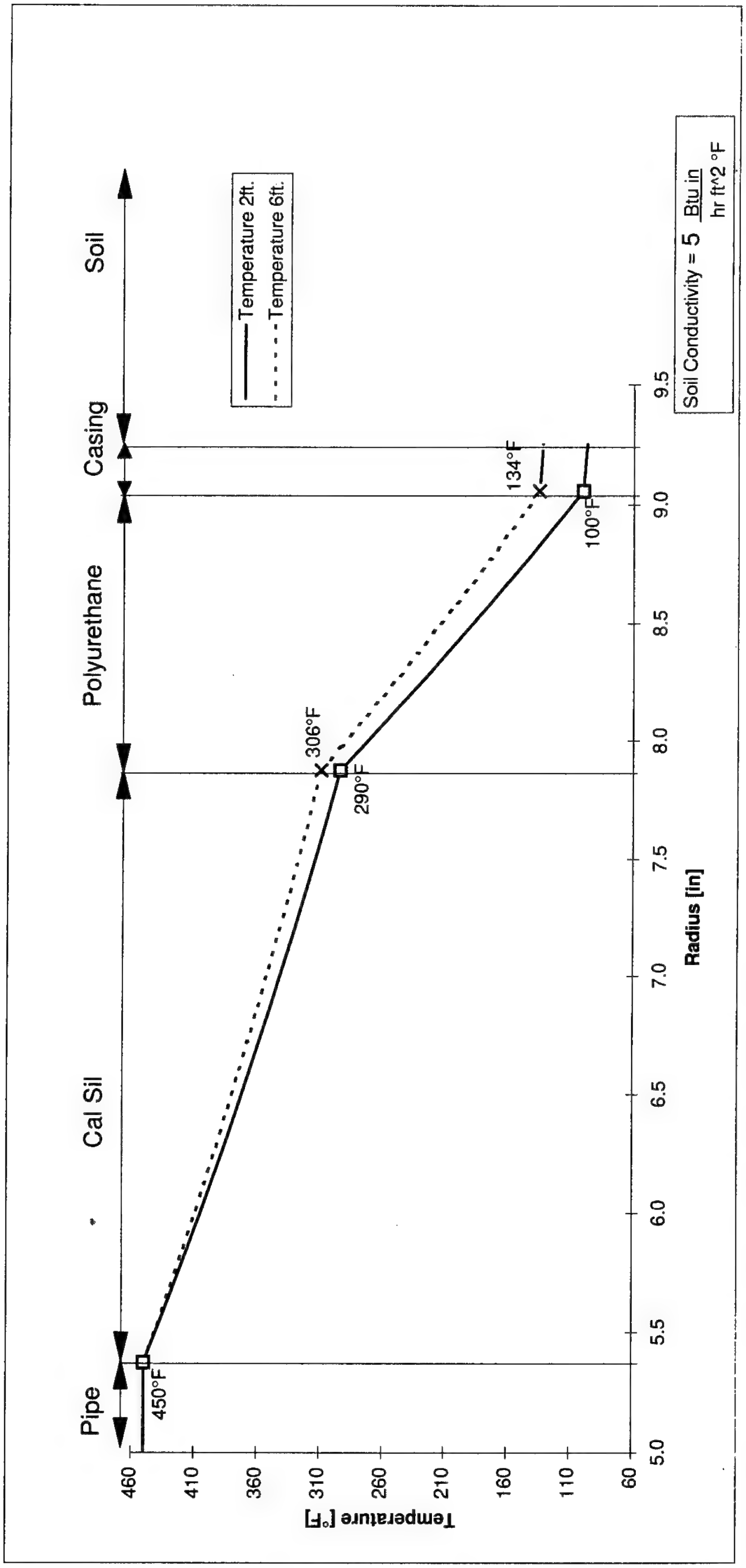

Figure B.23. 10 in. pipe at 450 °F (soil conductivity = 5).

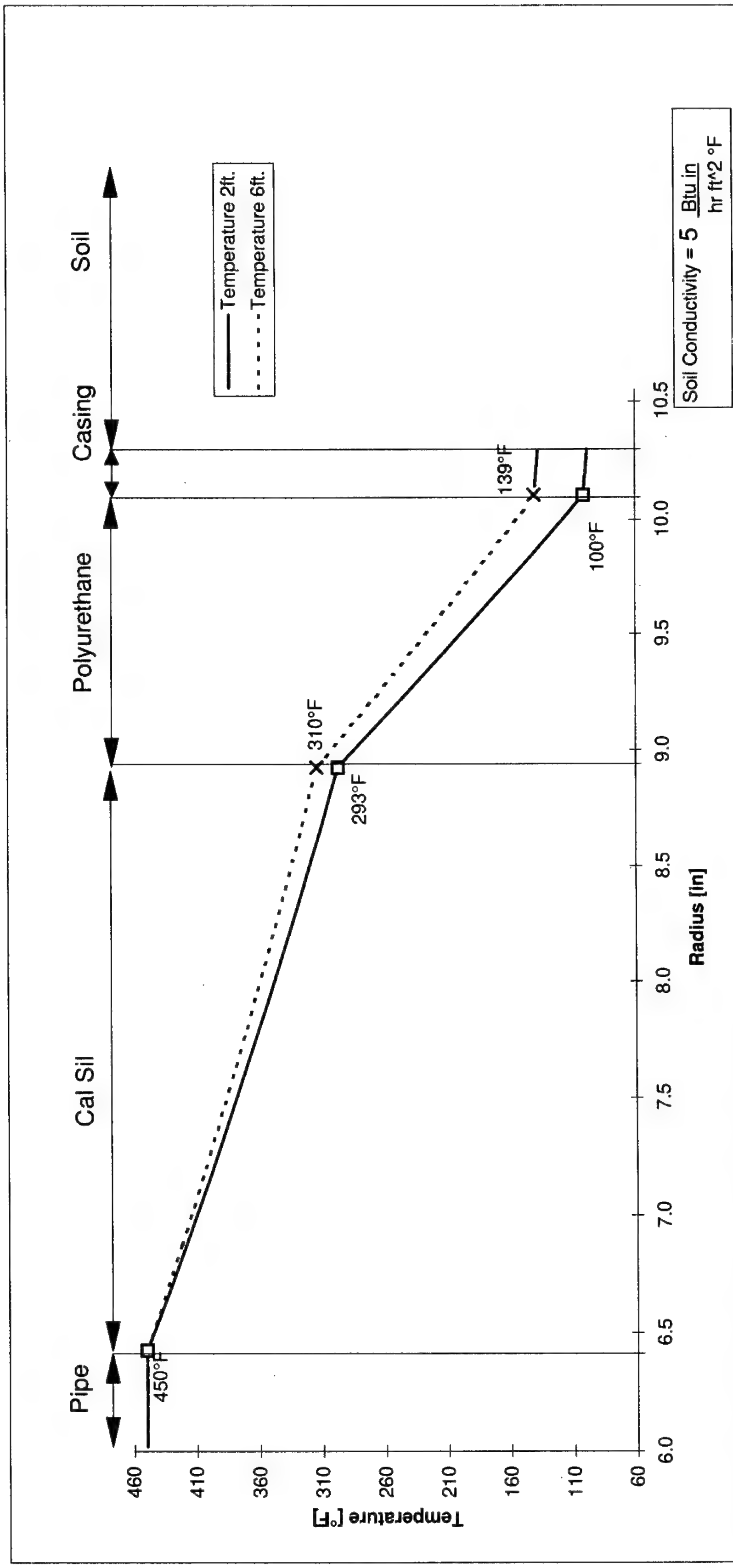

Figure B.24. 12 in. pipe at 450 °F (soil conductivity = 5).

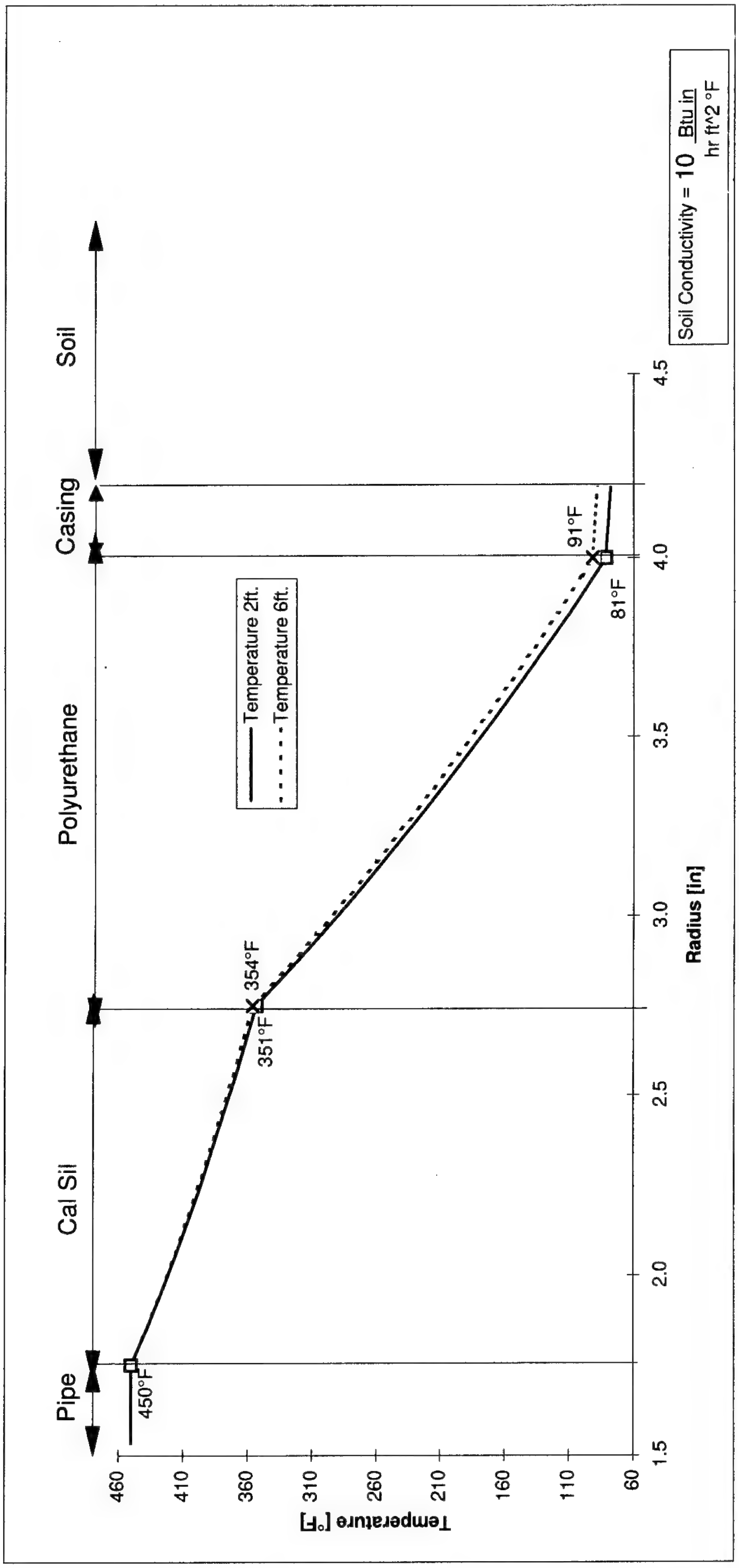

Figure B.25. 3 in. pipe at 450 °F (soil conductivity = 10).

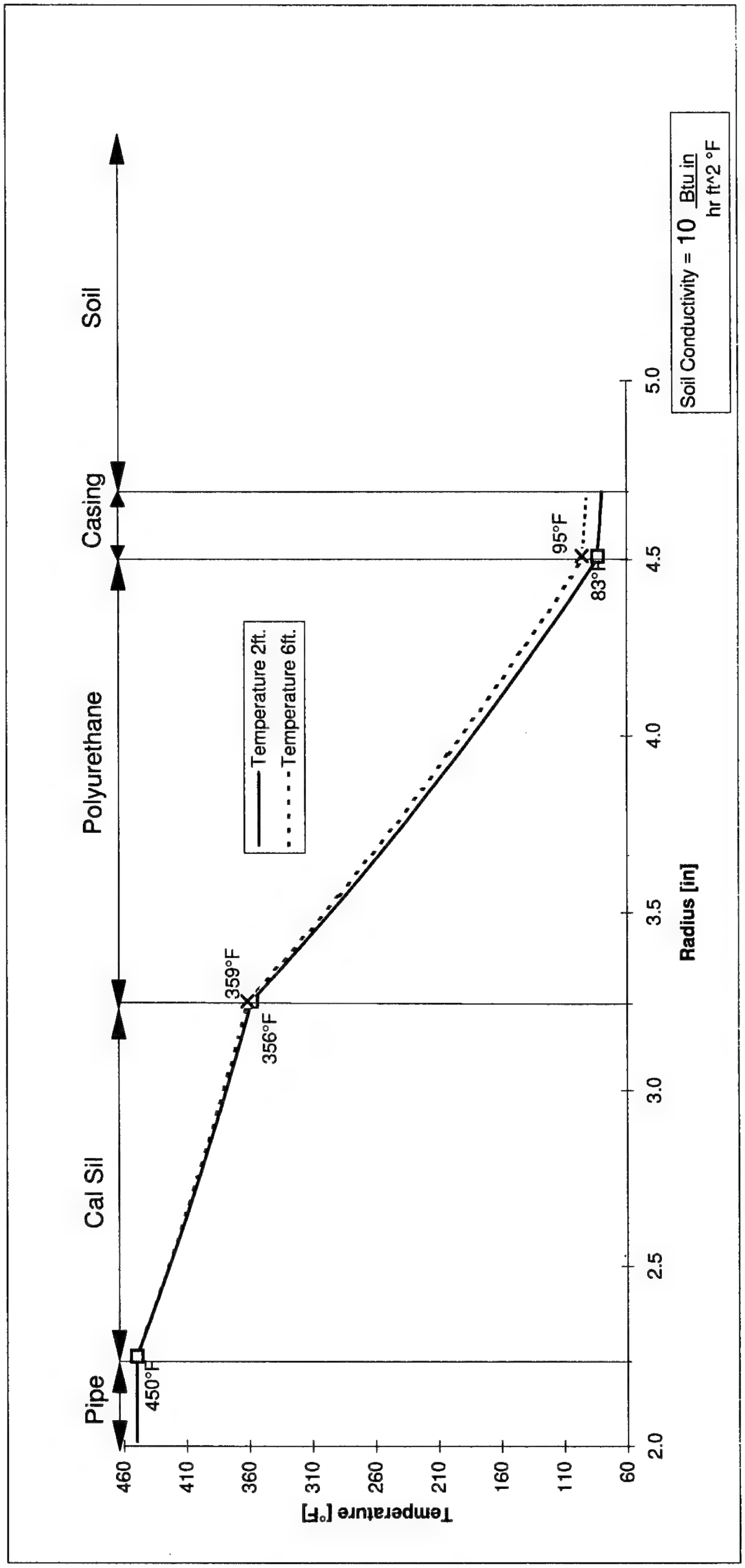

Figure B.26. 4 in. pipe at 450 °F (soil conductivity = 10).

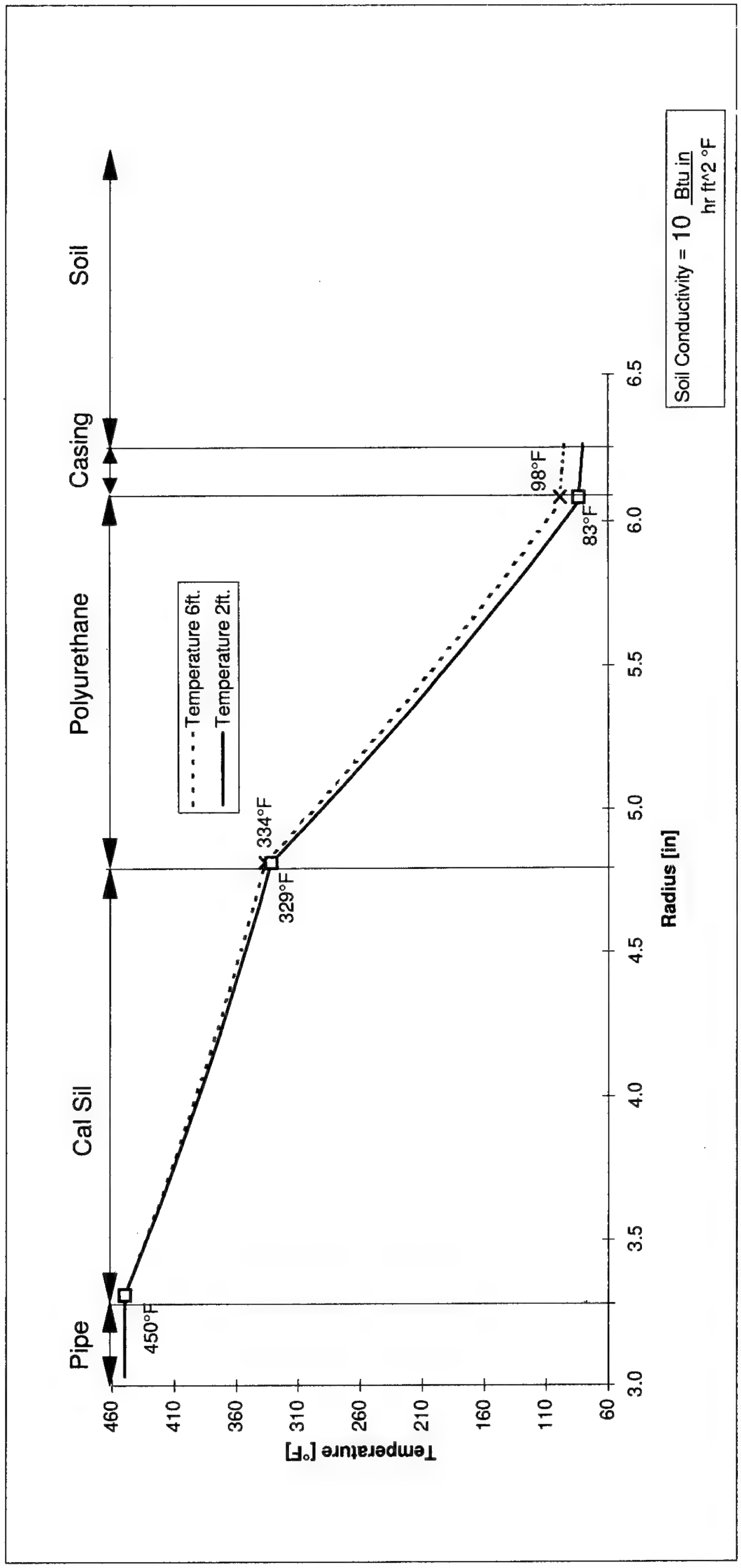

Figure B.27. 6 in. pipe at 450 °F (soil conductivity = 10).

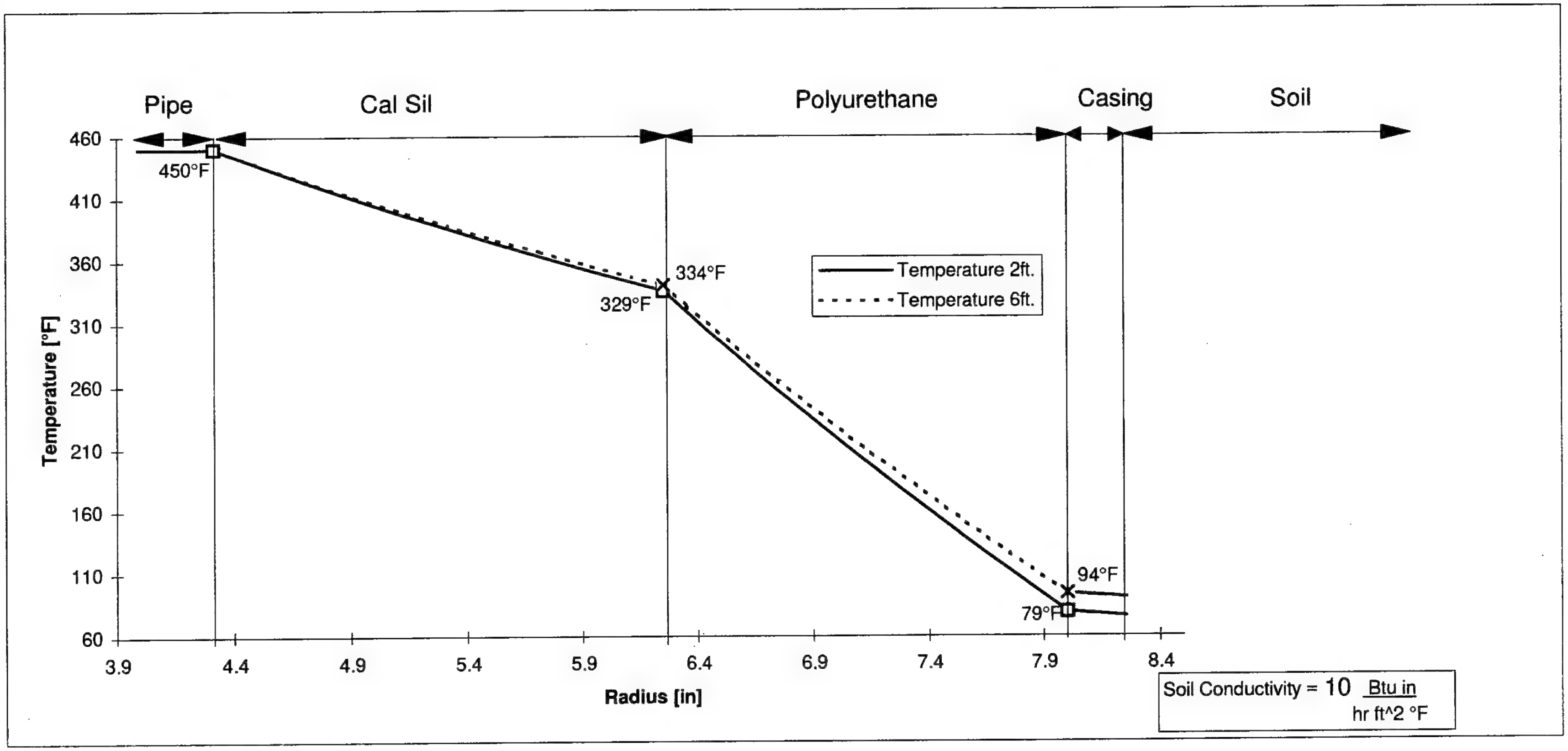

Figure B.28. 8 in. pipe at 450 °F (soil conductivity = 10).

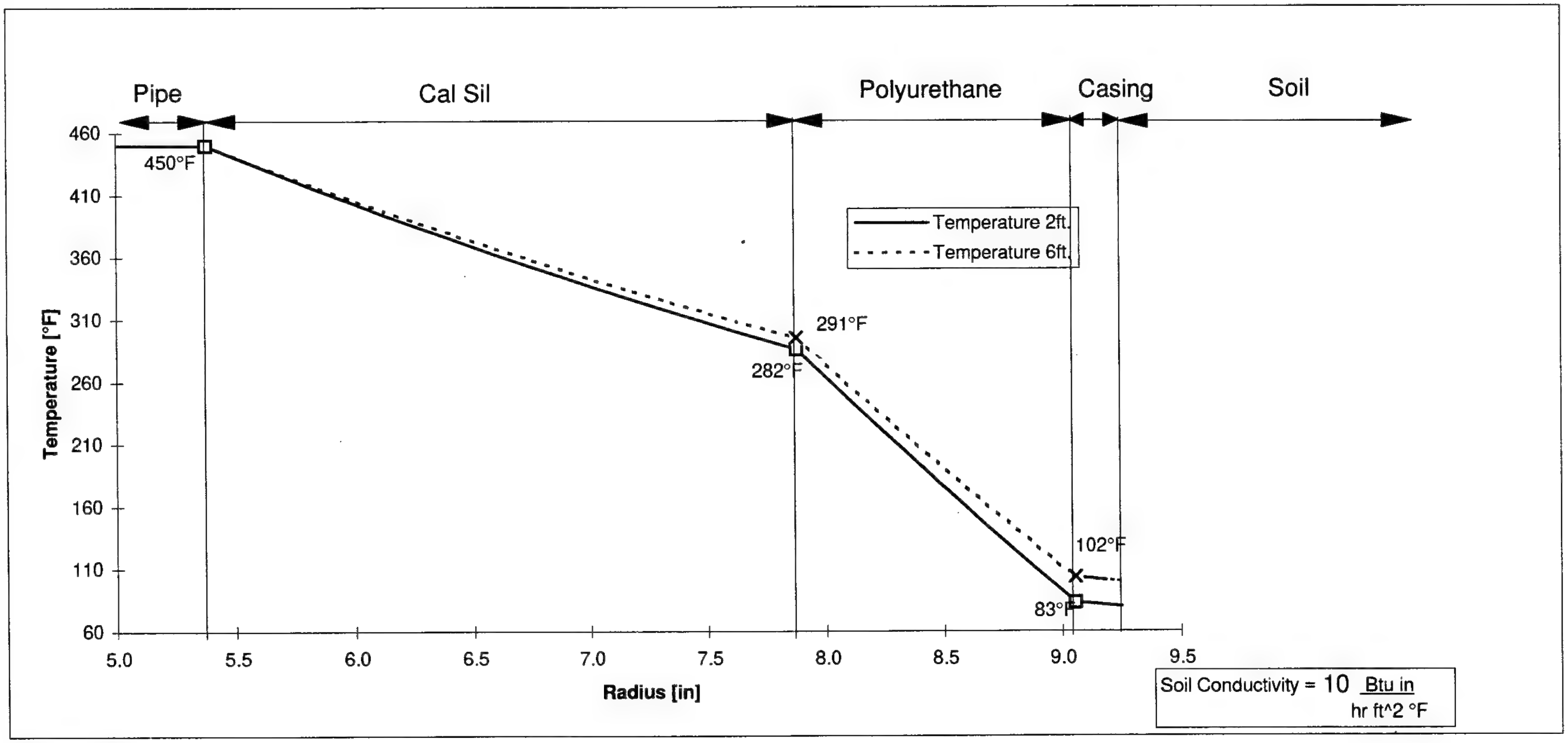

Figure B.29. 10 in. pipe at 450 °F (soil conductivity = 10).

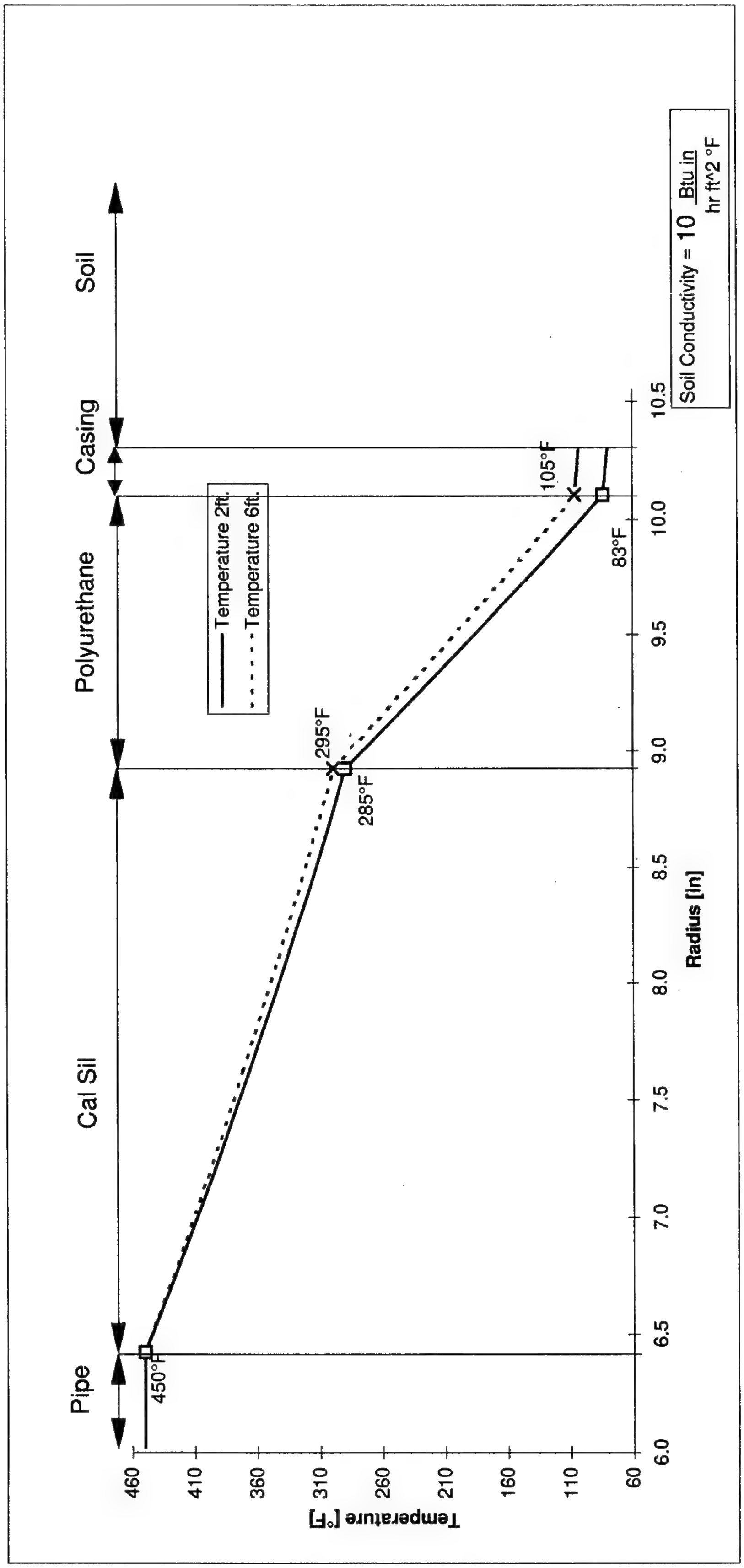

Figure B.30. 12 in. pipe at 450 °F (soil conductivity = 10).

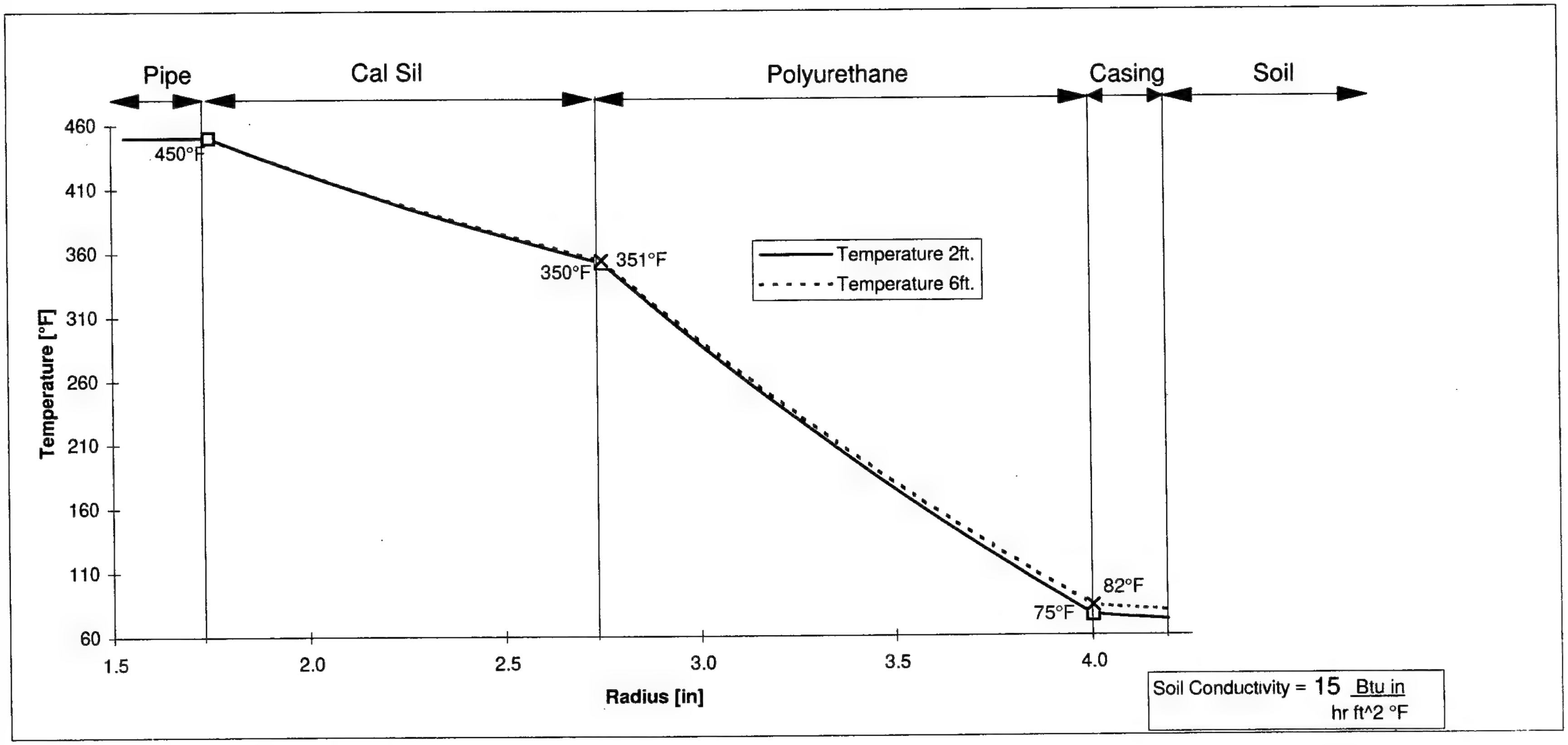

Figure B.31. 3 in. pipe at 450 °F (soil conductivity = 15).

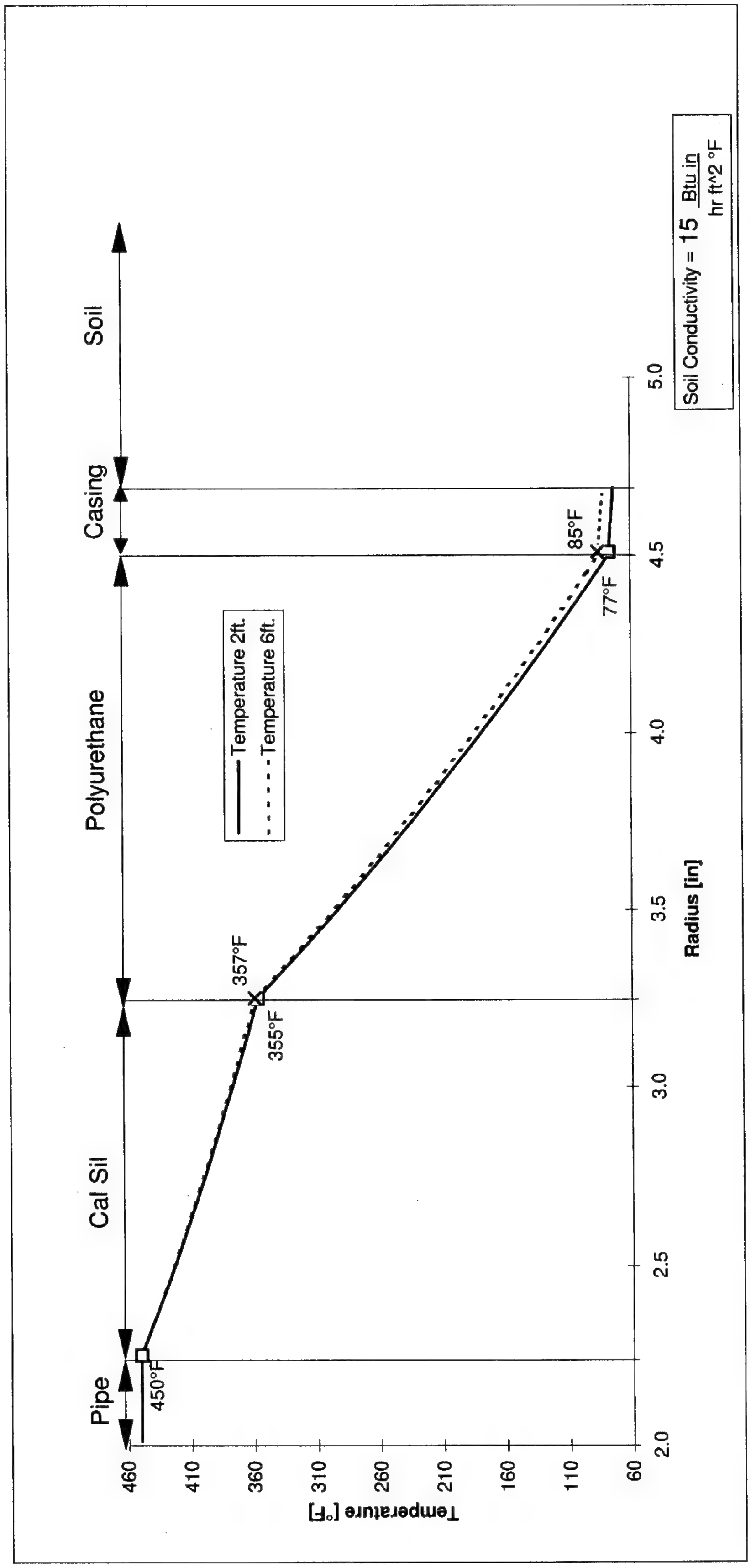

Figure B.32. 4 in. pipe at 450 °F (soil conductivity = 15).

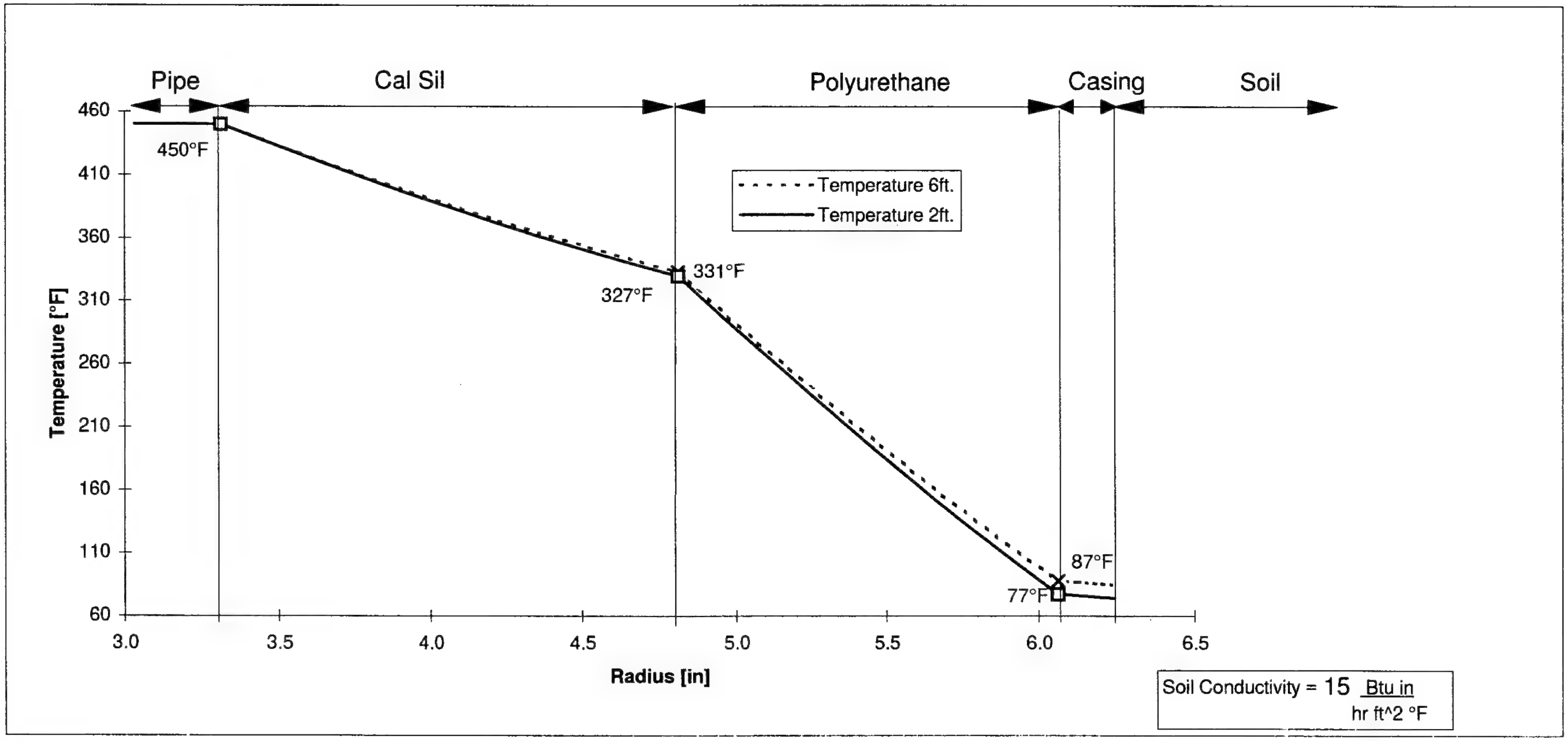

Figure B.33. 6 in. pipe at 450 °F (soil conductivity = 15).

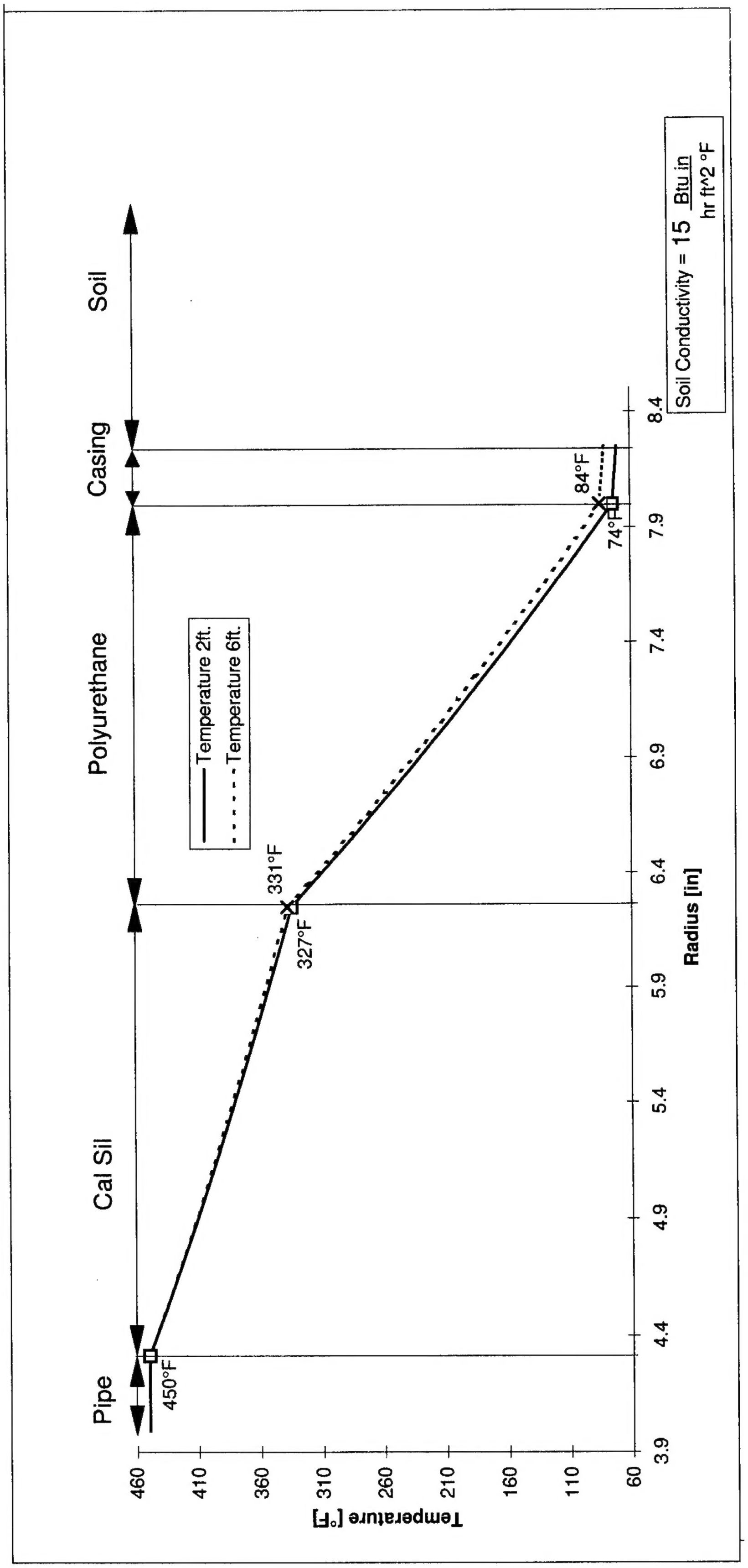

Figure B.34. 8 in. pipe at 450 °F (soil conductivity = 15).

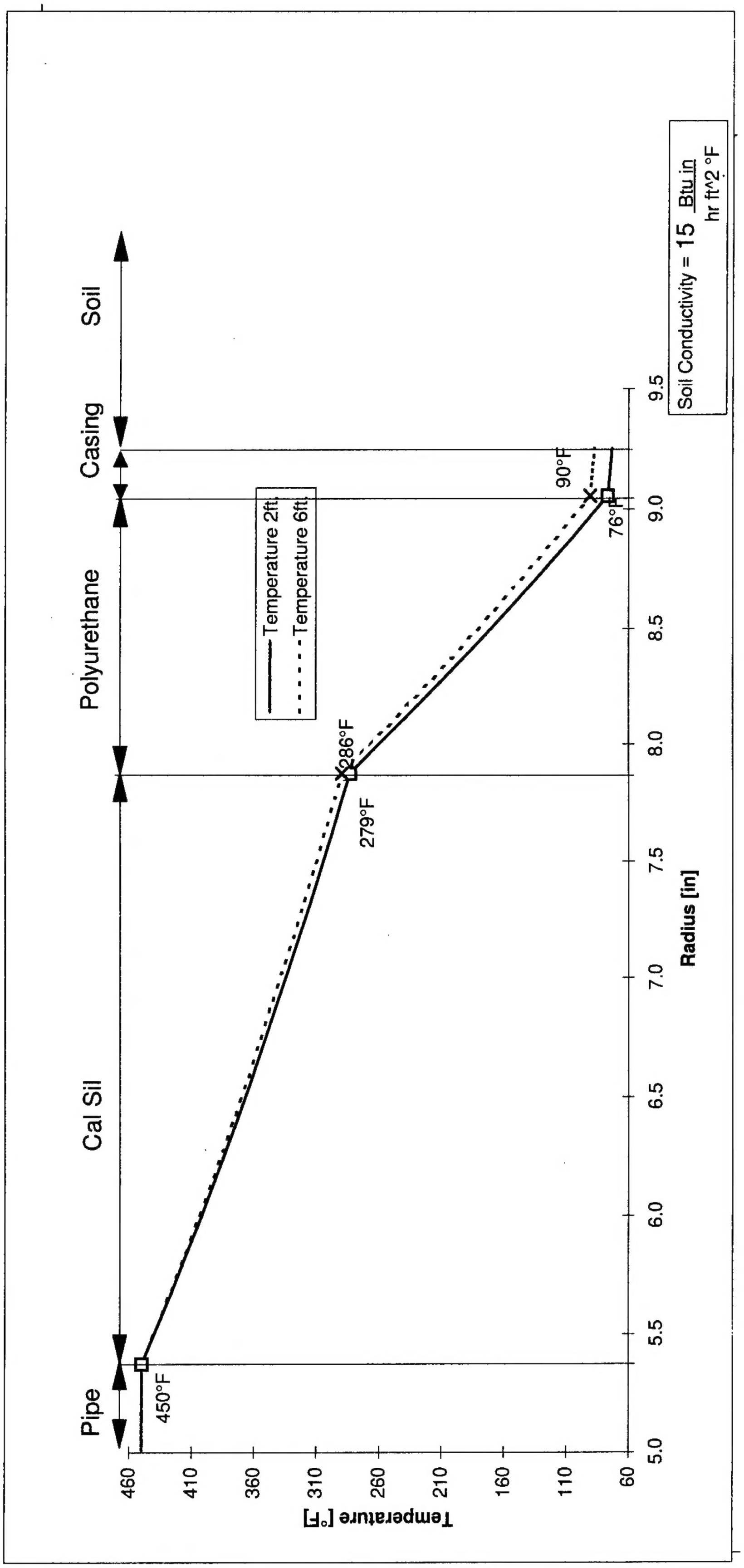

Figure B.35. 10 in. pipe at 450 °F (soil conductivity = 15).

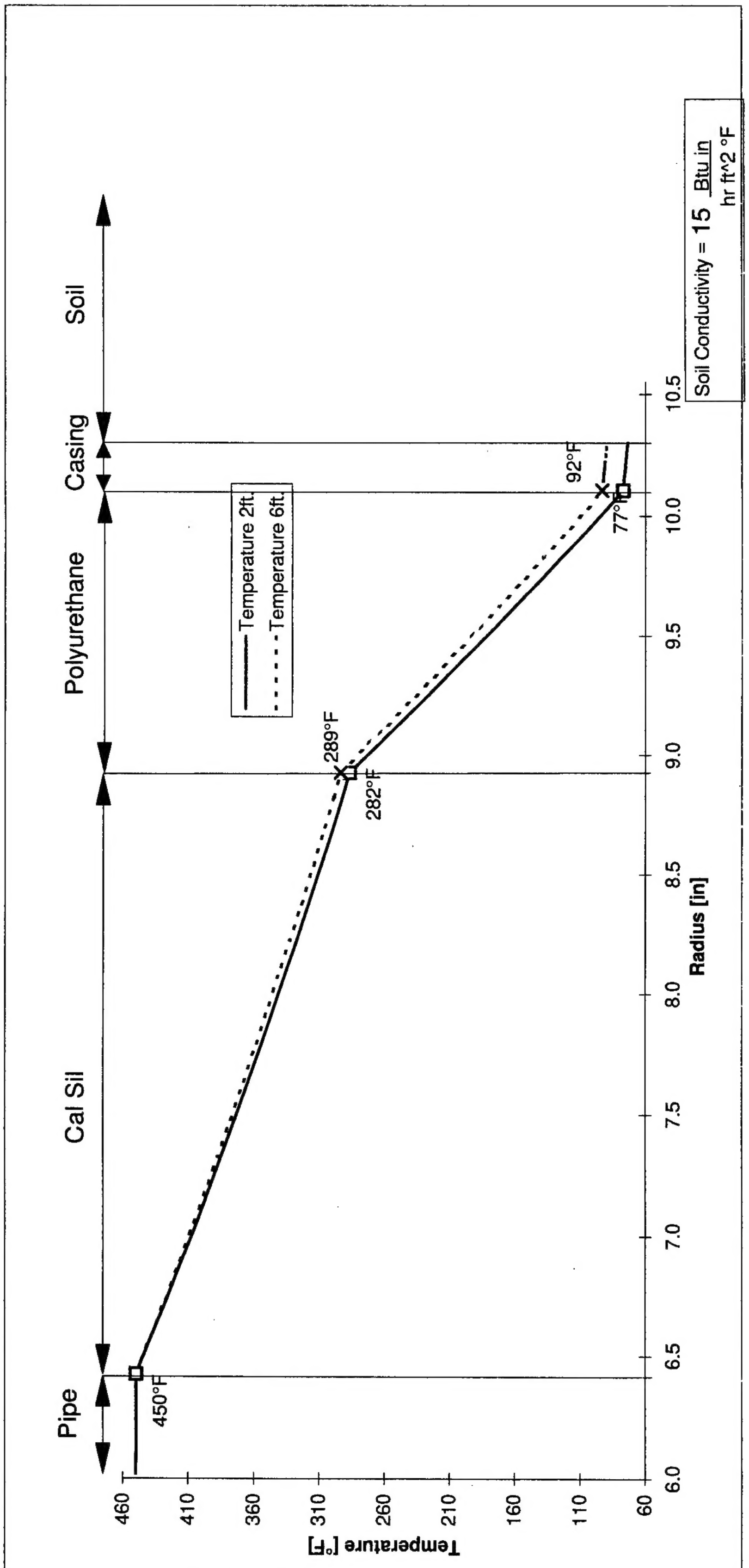

Figure B.36. 12 in. pipe at 450 °F (soil conductivity = 15).

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